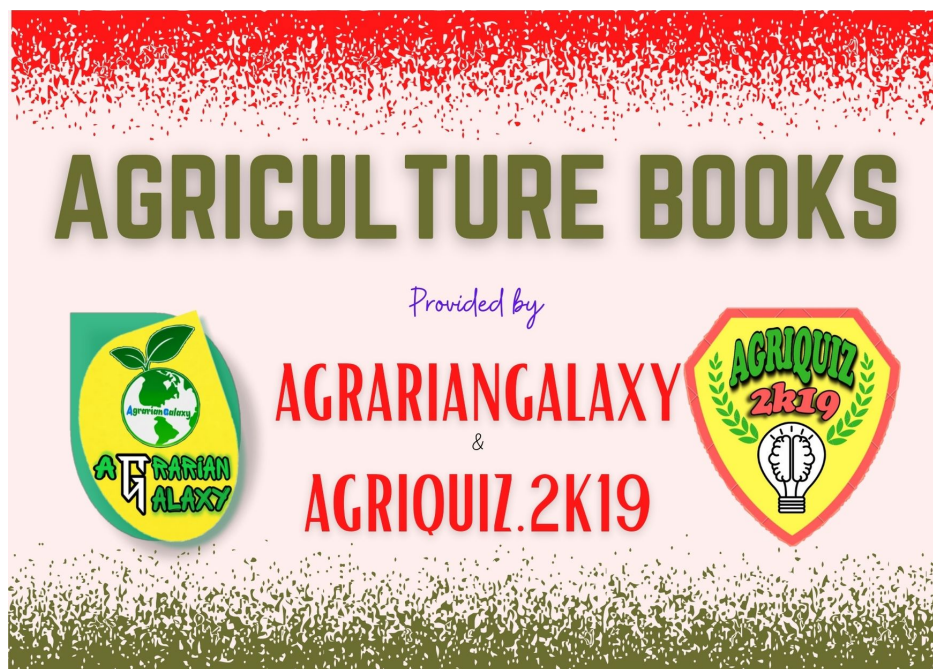


# *Handbook of* **Entomology**



Fourth Edition

# *Handbook of* **Entomology**

(For ARS Mains / SRF / UPSC / SAU Exams.)

Based on Revised Syllabus

Includes Previous Years ARS Subjective Papers

T. V. Prasad

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***Dedicated  
to  
Lord Venkateshwara***



# PREFACE

Entomology, one of the prominent branches of Agriculture has expanded by leaps and bounds during the last three decades and has assumed new dimension with respect to its different disciplines. Due to enormous breadth and diversity of the subject, a number of books have been written on various aspects of basic, general, applied and modern Entomology.

At present there is not even a single book available on Entomology subject that covers the entire syllabus of Entomology as per the revised ICAR prescription. The need for consolidating information on various topics of Entomology was felt since long to cater the needs of students appearing for various competitive examinations. It took many days to collect, compile, edit and update large wide spread literatures from various text books, reference books, journals, different websites, published literature, proceedings of various workshops, seminars, symposia, and reports of National and International institutes etc. to bring this piece of information in a readable shape. However, I should consider my labour well rewarded only if this book serves the needs of all concerned.

I acknowledge my humble indebtedness for all those authors from whose works information has been drawn.

I take this opportunity to thank our teachers, students, juniors and friends and special thanks to Sridhar, Gutam, Raju, Naveen, S R Kantwa, Manjunatha, Jaipal Singh Choudhary, Venkateswarlu, Muzeruddin Baig, Muttapa Yalawar, Deekshita, Sreelakshmi, Sravan Kumar and Sivaji who helped me to write this book.

I am also grateful to my family members for their love, patience, encouragement, moral support and bearing my absence after office hours, on holidays and my negligence towards the family responsibilities.

It is my great pleasure to express my sincere thanks to the publishers, New Vishal Publications, New Delhi who spared no pains in their efforts to produce this book of real quality within a short time

Criticism and suggestions for the improvement of the present book from teachers and students will be gratefully acknowledged. Feedback may be sent to tvprasad72@gmail.com.

Hyderabad

T V Prasad



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# **Agricultural Entomology**

## **Syllabus for various competitive examinations (ICAR JRF & SRF, IARI Ph.D. and ARS / NET)**

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### **ICAR JRF**

**SYLLABI FOR ICAR'S ALL INDIA ENTRANCE EXAMINATION FOR ADMISSION  
TO PG DEGREE PROGRAMMES AND ICAR- JRF (PGS)**

**Code 04: MAJOR SUBJECT GROUP "D" - ENTOMOLOGY AND NEMATOLOGY**

**(Subjects : D - 1 : Agricultural Entomology, D - 2 : Nematology, D - 3 : Apiculture, D - 4 : Sericulture, D - 5 : Plant Protection)**

**UNIT - I :** Importance of Agriculture in national economy; basic principles of crop production; cultivation of rice, wheat, chickpea, pigeon-pea, sugarcane, groundnut, tomato, and mango. Major soils of India, role of NPK and their deficiency symptoms. Structure and function of cell organelles; mitosis and meiosis; Mendelian genetics; elementary knowledge of photosynthesis; respiration, and transpiration; structure and functions of carbohydrates, proteins, nucleic acids, enzymes and vitamins. Major pests and diseases of rice, wheat, cotton, chickpea, sugarcane and their management. Important rural development programmes in India; organizational set up of agricultural research, education and extension in India; Elements of statistics.

**UNIT - II :** Classification of animal kingdom up to class-distinguishing characters up to orders in class Insecta; general organization of an insect with special reference to cockroach, butterfly and earthworm external morphology, different systems, metamorphosis; pests of field crops and stored products—their identification, biology, nature of damage; pests of medical and veterinary importance; pests of household importance and their control; important diseases caused by plant parasitic nematodes and their control; useful insects—honey bee, lac insect, silkworm; basic principles of insect pest control—cultural, biological, insecticidal; non-insect pests related to agriculture.

### **ICAR SENIOR RESEARCH FELLOWS (SRF)**

#### **PAPER - I : GENERAL KNOWLEDGE**

**Section 1 :** History and Geography of India—Events of significance with specific reference to scientific, cultural and economic life in India. General Awareness. Current events and analysis of their significance. Books, authors, persons, awards, places, projects, sports and athletics. Famous personalities and their achievements in Arts/Science/Social life and trends of thought. Major development programmes in India relating to poverty alleviation, agriculture, rural development etc. Five-Year Plans and their achievements—changes in the economic policies in the country and their impact on the agricultural scenario.

**Section 2 :** Agriculture in India. Basic information and data on the natural resources of the country; Agro-climatic and agro-ecological zones, Crops and their production; agricultural inputs and their use. Basic information on animal sciences and fisheries; Major breeds of livestock and their geographic distribution; Information on production and major recent achievements. Nutrition and agriculture—Basic information on foods and human nutrition. Quantitative analysis of data relating to agriculture/animal sciences/fisheries. Drawing of conclusions from data, based upon reasoning and logic. Policies in India relating to science, industry, agricultural, forestry. World trade agreement and its possible impact on Indian agriculture. Current trends and achievements in science and scientific research on the global scene. Recent scientific achievements of significance in the country in major areas and their impact on agriculture, animal and fisheries.

## PLANT PROTECTION AND RELATED SCIENCES (AGRICULTURAL ENTOMOLOGY)

**Section 1 : Systematics :** History and development of entomology. Position of insects in the phylum Arthropoda, relationship with other arthropods. Classification of insects up to order level. Habit, habitat and distinguishing characters of different orders. Distinguishing characters of families of economic importance. International code of zoological nomenclature. Body wall: structure, cuticular outgrowths, colouration and special integumentary structures. Body regions: sclerites and segmentation. Head: structure, types of mouth parts and antennae. Thorax sclerites and pterothorax. Wings, structure, venation, wing coupling and mechanism of flight. Legs: segmentation and types. Abdomen: segmentation and appendages. Genitalia and their modifications. Embryonic and post-embryonic development. Types of metamorphosis.

**Section 2 : Internal Anatomy and Physiology of Insects :** Structure, modification and physiology of different systems, digestive, circulatory, respiratory, excretory, nervous, reproductive, musculature and insect sense organs (mechano-, photo- and chemo-receptors). Physiology of moulting. Role of enzymes in growth and metamorphosis. Nutrition of insects, role of vitamins, proteins, carbohydrates, lipids and minerals. Extra and intra-cellular microorganisms.

**Section 3 : Ecology :** Principles of ecology, Environment and its components. Effect of biotic and abiotic factors on bionomics, distribution, abundance and natural balance. Inter- and intra-specific relationships. Dispersal and migration. Life table studies. Population models. Surveillance and forecasting. Causes of insect outbreaks

**Section 4 : Biological Control :** Principles and scope of biological control. Use of parasitoids, predators and pathogens. Introduction of exotic natural enemies. Conservation and augmentation. Mass production techniques and economics. Field release and evaluation. Host parasitoid relationships. Role of bacteria, fungi, protozoans and viruses; mode of action, mass production, formulation and field application.

**Section 5 : Insect - Host Plant Relationships :** Chemical ecology. Tritrophic relation. Role of mechano- and chemo receptors. Volatiles and secondary plant substances. Development of biotypes and measures to combat them. Breeding for insect-resistance in crop plants. Exploitation of wild species. Gene transfer. Case histories

**Section 6 : Toxicology :** Principles of toxicology. Classification of pesticides based on

chemical structure, mode of entry, and mode of action. Toxicity and structure activity relationships. Mode of action and therapeutic methods for control of poisoning of arsenicals, fluoro compounds, dinitrophenol, plant products (rotenoids, nicotinoids, neem), chlorinated hydrocarbons, organophosphates, carbamates, natural and synthetic pyrethroids, cartap, avermectin, chloridimeform etc. Systemic insecticides. Phyto-toxicity. Compatibility, antagonism and synergism. Factors affecting toxicity of insecticides. Insecticide resistance and resurgence. Insecticides Act 1968. Registration and quality control of insecticides. Bioassay methods. Plant protection appliances. Pesticide formulations. Hazards of pesticides to humans, domestic animals and wild life.

**Section 7 : Insect Vectors of Plant Diseases :** Role of insect vectors: aphids, leaf-hoppers, plant-hoppers, whiteflies, thrips, grass-hoppers and mites. Bacterial, viral, fungal and mycoplasma diseases and their transmission. Toxicogenic insects and phytotoxemia. Management of vectors.

**Section 8 : Pests of Crops and Stored Products and their Control :** Biology, nature, extent of damage and control of pests of paddy, sorghum, maize, millets, wheat, barley, pulses, fruits, vegetables, cotton and other fibre crops, tobacco, oilseeds, sugarcane, ornamental plants, plantation crops such as tea, coffee, coconut, arecanut, cashew, cocoa, spices and condiments like pepper, cardamom, clove, nutmeg and chillies. Stored products pests. Detection and estimation of infestation. Management of stored product pests. Evaluation and efficacy of storage structures. Polyphagous pests-locusts, termites, white grubs and hairy caterpillars and non-insect pests (mites, snails, birds and rats). Principles and components of integrated pest management. Economic thresholds. Economic injury levels. Action thresholds. Gain thresholds. IPM for important field and horticultural crops. Systems approach. Computer modelling. Case histories in IPM.

**Section 9 : Useful Insects :** Honey bees, lac insect and silk worms

## IARI Ph.D.

The Entrance Examination will be in the form of one question paper of three distinct parts. The questions will be of multiple choice and matching types in part I & II (30 marks and 150 marks respectively) and short analytical type in part III (30 marks). Answers for part I & II are to be given on computerized OMR answer sheets (see Annexure- VII) and that of part III in the space provided for the purpose in the question paper. Negative marking to the extent of 0.25 marks for each wrong answer will be applicable in case of part I and II of the question paper.

### PART - I : GENERAL AGRICULTURE

Importance of Agriculture in national economy; basic principles of crop production; cultivation of rice, wheat, pigeonpea, sugarcane, tomato, cauliflower, mango and rose. Weathering of rocks; soil formation, major soils of India, soil erosion and its control; common farm implements; role of NPK and their deficiency symptoms; manures (FYM, compost and green manure) and fertilizers (urea, diammonium phosphate, single super phosphate and muriate of potash). Structure and function and cell organelles - mitosis and meiosis; gametogenesis, fertilization and embryogenesis; chromosomal and extra-chromosomal basis of inheritance;

mutation and polyploidy; selection methods, hybridization, backcross; plant growth regulators; elementary knowledge of photosynthesis, respiration and nitrogen fixation. Isomerism; titrimetry and volumetry; structure and function of carbohydrates, proteins, nucleic acids, enzymes and vitamins. Major pests and diseases of rice, maize, pulses, oilseeds, vegetables, wheat, cotton, sugarcane and their management. Important principles of economics, structural transformation in economy and its globalization; principles of extension education; important rural development programmes in India; organizational set up of agricultural research, education and extension in India, elements of statistics.

## **PART - II AND III : SUBJECT PAPER : ENTOMOLOGY**

Position of insects in animal kingdom - their origin, phylogeny and distribution; history and basis of insect classification; distinguishing characters of insect Orders and economically important families; concept of species and speciation; rules and regulations of zoological nomenclature; morphology - external and internal; embryonic and post-embryonic development.

Insect ecology - biotic potential, biotic and abiotic resistance, effect of temperature, humidity and light on insect development and population dynamics; diapause, food chain, migration and dispersal.

Fundamentals of insect physiology, different systems, their structure and function, metabolism, sense organs, insect behaviour, host plant relationship. Social and other beneficial insects; pests of field crops and stored food; principles of pest control; classification, mode of action and metabolism of insecticides; insecticidal residues; resistance and resurgence; parasites, predators and pathogenic microorganisms of crop pests, biological control. Anti-feedants, hormones, growth regulators, semio-chemicals, host-plant resistance and genetic manipulation, insect quarantine; concept of integrated pest management; non-insect pests and their control

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## ARS / NET Examination

**Unit 1 : Systematics** : History and development of Entomology, Evolution of insects, position of insects in the animal world, characteristics of phylum Arthropoda, structural features of important arthropod groups such as Trilobita, Chelicerata and Mandibulata, structural features of important classes of phylum Arthropoda viz. Arachnida, Crustacea, Chilopoda, Diplopoda and Hexapoda. Classification of insects up to order level, habits, habitats and distinguishing features of different Order and important Families.

**Unit 2 : Morphology** : Body wall, its structure, outgrowths, endoskeleton, Body regions, segmentation, sclerites and sutures. Head and head appendages, types of mouth parts, antennae, their structure and types. Thorax structure, thoracic appendages and their modification. Wings, their modification and venation, Abdomen; structure, abdominal appendages both in Pterygota and Apterygota. External genitalia, general structure and modification in important insect orders.

**Unit 3 : Embryology, Internal Anatomy and Physiology** : Embryonic and post embryonic development, types of metamorphosis, physiology of ecdysis. General features and types of larvae and pupae. Structure, function and physiology of Digestive, Circulatory, Respiratory, Reproductive, Nervous and Excretory systems, Sense Organs; structure and types. Insect food and nutrition; minerals, carbohydrates, proteins and amino acids, lipids, vitamins and their role in growth and development, artificial diets.

**Unit 4 : Ecology** : Concept of ecology, Environment and its components-biotic and abiotic factors and their effects on growth, development, population dynamics, distribution and dispersal. Principle of biogeography and insects biodiversity. Biotic potential and environmental resistance. Ecosystems, agro-ecosystems analysis, their characteristics and functioning. Intra and inter specific relationship; competition, predator-prey and host-parasite interactions, ecological niche. Life table studies, population models. Food chain and food web. Arthropod population monitoring, pest forecasting. Diapause and causes of pest out breaks.

**Unit 5 : Biological Control** : Importance and scope of biological control, history of biological control: Bio-control agents parasites, predators and insect pathogens. Important entomophagous insect Orders and Families. Ecological, biological, taxonomic, legal and economic aspects of biological control, phenomena of multiple parasitism, hyper-parasitism, super-parasitism and their applied importance. Principles and procedures of using exotic Bio-control agents. Utilization of natural bio-control agents: conservation, habitat management and augmentation. Mass multiplication techniques and economics. Effective evaluation techniques, Bio-control organizations in world and India. Successful cases of biological control of pests.



Entomo-philic pathogens: bacterial, fungi, viruses, rickettsiae, Protozoan and nematodes, Modes of transmission, methods of uses, symptoms of infection. Microbial insecticides and their formulation. Merits and demerits of microbial control. Role of bio-control agents and microbial insecticides in Integrated Pest Management.

**Unit 6 : Chemical Control and Toxicology** : History, scope and principles of chemical control. Insecticides and their classification.

Formulations of insecticides. Susceptibility of insects to the entry of insecticides. Physical, chemical and toxicological properties of different groups of insecticides: chlorinated hydrocarbons, organophosphates, carbamates, synthetic pyrethroids, chlordimeform, chitin synthesis inhibitors, avermectins, nitroguandines, phenylpyrrozzoles, botanicals (natural pyrethroids, rotenone, neem products, nicotine, pongamia spp. etc). Combination insecticides. Problems of pesticide hazards and environmental pollution. Safe use of pesticides, precautions and first aid treatments. Insecticides Act 1968, registration and quality control of insecticides. Evaluation of toxicity, methods of toxicity testing, determination of LD 50, LT 50, RL 50 etc. Pesticides residues in the environment and their dynamics of movements, methods of residue. Pharmacology of insect poisons. Mode of action of different groups of insecticides; neuroactive (axonal and synaptic) poisons, respiratory poisons, chitin synthesis inhibitors. Metabolism of insecticides; activative and degradative metabolism, detoxification enzymes and their role in metabolism. Selectivity of insecticidal actions; insecticide resistance; mechanism, genetics and management of insecticide resistance.

**Unit 7 : Host Plant Resistance** : Chemical ecology: mechano and chemo receptors. Host plant selection by phytophagous insects. Secondary plant substances and their defenses against phytophagous insect. Basis of resistance (Antixenosis, Antibiosis, Tolerance). Biotypes development and its remedial measures. Tritrophic interactions, induced resistance. Breeding for insect resistant plant varieties. Resistance development and evaluation techniques. Genetics of Resistance: vertical resistance, horizontal resistance, oligogenic resistance, polygenic resistance. Biotechnological approaches and development of transgenic insect resistant plants, its advantages and limitations. Case histories. Insect resistance to transgenic plants and its management.

**Unit 8 : Innovative Approaches in Pest Control** : Behavioral control: pheromones-types and uses, advantages and limitations. Hormonal control: types and function of insect hormones, insect hormone mimics, advantages and limitations. Chemo-sterilants, anti-feedants, attractants, repellents; their types, method of applications, advantages and limitations. Genetic control: concepts and methods, case histories, advantages and limitations. Potentialities of IPM.

**Unit 9 : Integrated Pest Management** : History, concept and principles of IPM. Components of IPM: Host plant resistance, agronomic manipulations, mechanical and physical methods, chemical methods, Bio-control agents utilization, genetic and behavioral control strategy etc. IPM strategies for field and horticultural crops. IPM case histories. Concept of damage levels- Economic threshold levels (ETL), Economic injury levels (EIL) and their determination. System approach, Agro ecosystem and cropping system *vs.* IPM. Constraints and Strategies of IPM implementation.

**Unit 10 : Pesticide Application Equipments** : Types of appliances: sprayers, dusters, fog generators, smoke generators, soil injecting guns, seed treating drums, flame throwers, etc. Power operated sprayers and dusters. Types of nozzles and their uses. Maintenance of



appliances. Aerial application of pesticides, principles of aerial application, factors affecting the effectiveness of aerial application. Equipments for aerial applications. Advantages and disadvantages of aerial application.

**Unit 11 : Pests of Field Crops and their Management** : Distribution, host range, biology and bionomics, nature of damage and management of arthropod pests of cereals, Oilseed, pulses and fibre crops, sugarcane and tobacco. Polyphagous pests: locusts, termites, hairy caterpillars, cut worms and white grubs.

**Unit 12 : Pests of Horticultural Crops and their Management** : Distribution, host range, biology and bionomics, nature of damage and management of arthropod pests of vegetables, fruits and plantation crops, spices, condiments and ornamentals.

**Unit 13 : Pests of Stored Products and their Management** : Fundamentals of storage of grains and grain products. Storage losses, sources of infestation/infection, factors influencing losses, insect and non-insect pests, their nature of damage and control. Microflora in storage environment and their control. Storage structures, bulk storage and bag storage, their relative efficacy and demerits. Grain drying methods and aeration. Non-insect pests (rodents, birds, mites) of stored products and their control. Integrated management of storage pests.

**Unit 14 : Arthropod Vectors of Plant Diseases** : Common arthropod vectors *viz.*, aphids, leaf hoppers, plant hoppers, whiteflies, thrips, psyllids, beetles, weevils, flies, bees and mites and their relationship with the plant pathogenic fungi, bacteria, viruses, mycoplasma. Mechanism of pathogen transmission : Active mechanical transmission, biological transmission. Toxicogenic insects, mites and phytotoxemia. Some important arthropod vector transmitted diseases and their epidemiology in India. Management of vector and its effect on control of diseases.

**Unit 15 : Honey Bees and Bee -keeping** : Honey bees and their economic importance. Bee species, their behaviour, habit and habitats. Bee Keeping: bee pasturage, hives and equipments, seasonal management. Bee enemies including diseases and their control.

**Unit 16 : Silkworms and Sericulture** : Silkworm species, their systematic position and salient features. Rearing techniques of mulberry, muga- eri and tassar silkworms. Nutritional requirements of silkworms. Sericulture: rearing house and appliances, silkworm breeds, principles of voltinism and bivoltinism, seed production and its economics. Enemies and diseases of silkworms and their management. Sericulture organization in India.

**Unit 17 : Lac Insect** : Lac insect, its biology, habit and habitats. Host Trees: pruning, inoculation, lac cropping techniques, and harvesting. Enemies of lac insect and their control.

**Unit 18 : Other Useful Insects** : Pollinators, Bio-control agents of weeds, soil fertility improving agents, scavengers. Use of insects and insect products in medicines. Usefulness of insects in scientific investigations, insects as food.

**Unit 19 : Statistics and Computer Application** : Frequency distribution, mean, mode and median. Standard, normal, binomial and Poisson's distribution, Sampling methods and standard errors. Correlation and regression: Partial and multiple, tests of significance; t, F, chi- square, Duncan's multiple range tests. Design of experiments: Principles of Randomized block design, Completely randomized block design, Latin square design, Split-plot designs. Probit analysis. Use of soft ware packages like SPSS, SAS, etc. for the above tests and designs of experiments for analysis.



# Systematics

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## 1.1 CLASSIFICATION OF PHYLUM ARTHROPODA

### Arthropod classification

Phylum Arthropoda is divided into

- Subphylum Trilobita – (Marine fossils only)
- Subphylum Chelicerata – Chelicera and pedipalps
  - Class Merostomata
  - Order Xiphosurida - King or horse shoe crabs
  - Order Eurypterida – Sea scorpions (Fossils only)
  - Class Pycnogonida – Sea spiders
  - Class Arachnida – Spiders, scorpions, mites, ticks
    - Order Araneae – Spiders
    - Order Scorpionida – Scorpions
    - Order Acari – Mites and ticks
- Subphylum Crustacea – Crabs, lobsters, shrimp, isopods, water fleas, etc.,
  - Class Branchiopoda – Fairy shrimp, brine shrimp
  - Class Maxillopoda – Copepods
  - Class Malacostraca
    - Order Isopoda – Sow bugs
    - Order Amphipoda – Side swimmers, scuds
    - Order Decapoda – Crabs, true shrimp, lobsters, crayfish
- Subphylum Uniramia
  - Class – Chilopoda – Centipedes
  - Class - Diplopoda – Millipedes
  - Class – Symphyla – Green house centipedes

- Class – Pauropoda – Pauropods
- Class – Insecta (Hexapoda)
- Class – Onychophora

Mandibulata, comprises the extant subphyla Myriapoda, Crustacea and Hexapoda  
Myriapoda includes Chilopoda, Diplopoda, Symphyla and Pauropoda

## 1.2 CHARACTERISTICS OF PHYLUM ARTHROPODA

- **The principal characters of Phylum Arthropoda are**
- The body is segmented, the segments usually grouped in 2 or 3 rather distinct regions
  - Paired segmented appendages (thus name Arthropoda)
  - Bilateral symmetry
  - A chitinous exoskeleton, which is periodically shed and renewed as the animal grows
  - A tubular exoskeleton, with mouth and anus
  - Open circulatory system
  - The body cavity is a blood cavity or haemocoel, the coelom is reduced
  - The nervous system consisting of anterior ganglion or brain located above the alimentary canal
  - The skeletal muscles striated (except Onychophora)
  - Excretion usually by means of Malpighian tubules
  - Respiration by means of gills or trachea and spiracles
  - No cilia or nephridia (except Onychophora)
  - The sexes are nearly always separate

## 1.3 CHARACTERISTICS OF TRILOBITA, CHELICERATA AND MANDIBULATA

- **Important features of sub phylum Trilobita**
- The Trilobites are marine fossils lived during the Paleozoic era but were most abundant during the Cambrian and Ordovician periods
  - The body is usually oval and dorsoventrally flattened. It is divided transversely into 3 regions (head, thorax and pygidium) and longitudinally into 3 lobes (two lateral pleura and a median axis)

- The head bears a pair of antennae, compound eyes and 4 pairs of biramous appendages. It is covered by a carapace
- A pair of identical biramous appendages is found on each thoracic segment

➤ **Important features of sub phylum Chelicerata are**

- These arthropods lack antennae and typically have six pairs of appendages- the first being chelicerae and the rest being leg like
- The body is divisible into cephalothorax anteriorly and posterior abdomen
- Cephalothorax bears chelicerae and leg like appendages
- The genital ducts open to the outside near the anterior end of the opisthosoma (abdomen)
- Most chelicerates have an extra leg segment the patella, between the femur and tibia
- The legs are usually uniramous, that is there is exite or exopodite

➤ **Important features of Mandibulate Arthropods are**

- The arthropods with mandibles form the clade Mandibulata, comprising the extant subphyla Myriapoda, Crustacea and Hexapoda so named because its members possess a pair of mandibles as the primary masticatory organs
- In arthropods, the mandibles are used for biting, cutting and holding food and are often simply referred to as jaws
- Mandibulates also differ by having antennae, and also by having three distinct body regions: head, thorax and abdomen
- The crustacea are clearly very distinct from the other groups by the virtue of their two pairs of antennae
- The myriapods and hexapods possess a single pair of antennae hence these are grouped in Uniramia (along with Onychophora)

➤ **Important features of Order Xiphosurida of sub phylum Merostomata are**

**Horse shoe crabs - example *Limulus polyphemus***

- Cephalothorax is covered with a horse shoe shaped carapace
- The abdomen articulates freely with the cephalothorax and at its posterior end carries a long telson
- On the ventral side of the cephalothorax are 6 pairs of limbs. The most anterior part are the chelicerae and these are followed by 5 pairs of legs
- Six pairs of appendages are found on the abdomen

➤ **Important features of Order Eurypterida (Giant water scorpions) are**

- These are extinct group of predatory Arthropoda which existed from the Cambrian to Permian periods
- The eurypterids appeared at the beginning of the Ordovician Period (about 488 million years ago) and became extinct at the end of the Permian Period (about 251 million years ago).
- They were aquatic, similar to Xiphosura and some reached a length of over 2 meters
- Six pairs of limbs occur on the cephalothorax, a pair of chelicerae, the second pair is often greatly enlarged and chelate forming pedipalps which presumably served in defence and to capture the prey
- A pair of simple and compound eyes
- The opisthosoma was 12 segmented

➤ **Important features of sub class Pycnogonida (Sea spiders) are**

- The pycnogonids are marine, spider like forms with long legs
- They are predaceous and have a sucking proboscis on the cephalothorax
- The body consists of cephalothorax and very small abdomen and lack appendages
- Cephalothorax bears a raised tubercle bearing four simple eyes, a pair of chelicerae and an associated pair of palps and five pairs of legs
- The first pair of legs (ovigerous legs) are used in males for carrying the eggs

#### **1.4 CHARACTERISTICS OF ARACHNIDA, CRUSTACEA, CHILOPODA AND DIPLOPODA**

➤ **Important features of class Arachnida are**

- The class Arachnida includes scorpions, spiders, ticks and mites
- The body has two distinct regions, cephalothorax and abdomen
- They do not have antennae and compound eyes
- Simple eyes are present
- They have well developed palps on the head and possess 4 pairs of legs on the thorax and use for walking
- Terrestrial animals and breath by means of air tubes or book lungs

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- The sexes are separate and reproductive organs are near the anterior portion of the abdomen and open through a single orifice
- Order Araneae includes spiders
- Order Scorpionida includes scorpions
- Order Acari includes mites and ticks

### ➤ Differences between ticks and mites

| Ticks                                                                                                                                                                                                                 | Mites                                                                                                                                                                                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| These are larger than mites<br>These have leathery skin<br>The body is not covered by hairs<br>These are blood suckers and carriers of diseases<br>Ex : Black - legged tick or deer tick,<br><i>Ixodes scapularis</i> | These are microscopic<br>These have soft body<br>Body is covered by hairs / spines<br>These are both phytophagous parasites / predators / animal parasites<br>Ex : <i>Acarapis woodi</i> on honey bees |

### ➤ Important features of sub phylum Crustacea are

(Crabs, lobsters, shrimps, prawns, barnacles and woodlice)

- These are primarily aquatic, body divided into cephalothorax and abdomen
- Cephalothorax with two pairs of antennae, 3 pairs of mouth parts (mandibles and 1<sup>st</sup> and 2<sup>nd</sup> maxillae) and at least 5 pairs of legs, biramous appendages
- There is typically a terminal telson
- The cephalothorax in many crustaceans is covered by a shield like portion of the body wall called the carapace
- They breathe by means of gills, except the small forms which breathe through the body wall
- The sexes are separate and the genital openings are generally in pairs

### ➤ Important features of Myriapoda are

- The members of 4 groups of mandibulate arthropods (Chilopoda, Diplopoda, Pauropoda and Symphyla) have a body composed of 5 or 6 segments head and elongate trunk that bears many pairs of legs and they are found in similar habitats
- For these reasons they were traditionally placed in a single large taxon, the

### Myriapoda

- They possess single pair of antennae, a tracheal respiratory system, Malpighian tubules for excretion and absence of compound eyes

#### ➤ **Characteristics of Chilopoda are**

- These are commonest myriapods
- These include centipedes
- These are typically active, nocturnal predators whose bodies are flattened dorsoventrally
- The first pair of trunk appendages (maxilipeds) are modified into poison claws that are used to catch prey
- In most centipedes the legs increase in length from the anterior to posterior of the animal to facilitate rapid movement
- These have one pair of legs on every segment of the body

#### ➤ **Characteristics of Diplopoda are**

- These include millipedes
- Each segment bears two pairs of legs
- These are slow moving primarily herbivorous animals
- Since they can not escape from predators by speed, many millipedes have evolved such protective mechanisms as the ability to roll into a ball and they secrete defensive chemical
- These are elongated worm like creatures, their body is rounded and the segments are internally fused in two's
- The antennae are short and there is no poison claws

#### ➤ **Characters of Pauropoda are**

- These are minute arthropods that live in soil and leaf mould
- A large tergal plates on the trunk which overlap adjacent segments is a characteristic feature

#### ➤ **Characters of Symphyla are**

- Symphylans are small arthropods that differ from other myriapods in the possession of a labium, and the position of the gonopore (on the 11<sup>th</sup> body segment)
- At the base of the legs of symphylans have eversible vesicle and coxal styli

## 1.5 CHARACTERISTICS OF HEXAPODA

### ■ Characters of Class Hexapoda (Insecta)

The distinguishing characters of the hexapoda are

#### **Body**

- The body with three distinct regions, head, thorax and abdomen

#### **Head**

- One pair of antennae (rarely no antennae)
- One pair of mandibles
- One pair of maxillae
- A hypo pharynx
- A labium

#### **Thorax**

- Three pairs of legs, one on each thoracic segment
- Two pairs of wings or often one borne by the second and/or third of the 3 thoracic segments

#### **Abdomen**

- The gonopore (rarely two gonopores) at the posterior end of the abdomen
- No locomotor appendages on the abdomen of the adult
- Abdominal appendages if present consists of a pair of cerci, an epiproct and a pair of paraprocts

## 1.6 EVOLUTION OF INSECTS

Evolution relationships among the arthropods are unclear, although there have been a number of opinions expressed. Some investigators argue that the arthropods are a polyphyletic group and that many of their similarities have arisen as a result of convergent evolution. However, others see them as clearly monophyletic, having evolved from a common ancestor.

At least five major theories of the ancestry of insects exist, with one (or more) leading evolutionist arguing for each. These include the speculation that the ancestor common to all insects was an annelid or annelid-like creature that looked something like a modern earthworm.



Class Insecta is also assumed by many authorities to have evolved from a myriapod (millipede) or some type of protomyriapod animal during the Devonian period, but even this conclusion about insect origins is controversial.

Meglitsch and others have concluded that the segmented worms ‘apparently evolved from the ancient protostomes, which also gave rise to the mollusks’ and were the ancestors of insects. But Labandeira discounts this view, and instead argues on the basis of bio-molecular studies that insects and other hexapods evolved ‘from an unspecified lineage of crustaceans’. He admits that ‘hexapod origins remains unsettled’, and that morphological evaluations still favour a non-crustacean ancestor.

Although the most common view is that insects evolved from some type of myriapod, Romoser and Stoffolanon concluded it is more likely that myriapods and insects both evolved from some unknown common ancestor. Other evolutionists argue that ‘it is reasonable to suppose that’ the earliest insects ‘were similar to silverfish’, an animal that appears in the fossil record an estimated 350 million years ago.

The lack of transitional forms is a major reason why phylogenetic trees vary so drastically. Furthermore, the dominant view of insect evolution (from myriapods) is not supported by RNA analysis. ‘One major difference is that the limbs of crustaceans are branched (biramous) whereas those of insects and myriapods are always unbranched, even in their embryonic stages – hence their new name “Uniramia”’. Chelicerates also have unbranched set of mouthparts, in particular a pair of pincerlike structures called chelicerae. Finally there are fundamental differences between the groups in the way the legs and jaws move, which suggest that each developed limbs independently. ‘Of the ancestors themselves, little is known, and only the worm-like onychophorans provide any real evidence. The construction of their body wall and excretory system is distinctly annelid-like, but they also have appendages that could have been the forerunners of the insects’ segmented limbs, as well as insect-like antennae, and tracheae for breathing.

All this suggests that the Uniramia evolved from annelid stock, but the ancestors of the other groups—the crustaceans and chelicerates—remain a complete mystery.’ The great advantage of using insect fossils to test evolution is that most insects have exoskeletons, and consequently their external morphology is usually well preserved.

## 1.7 THEORIES ON EVOLUTION OF INSECTS

Theories of insect origin have included attempts to derive insects from Onychophora, Annelida, Trilobites, larvae of Crustacea, and Chilopods.

**Different theories of insect’s origin are**

1. **Muller theory (1864)** : He thought that the insects had descended from species resembling zoea larvae of Crustacea, having cephalothorax, 3 pairs of mouth appendages and same number of legs

2. **Braver theory (1868)** : He considered that the insects origin to be from a myripod like ancestor
3. **Handlirsch theory (1908)** : He argued that insects have evolved from Trilobita.
4. **Hesen theory (1930)** : He considered that insects had originated from Crustacea.
5. **Tillyard theory (1930)** : He believed that insects and myriapods had decended from a common collembolan like ancestor which is called protaptera.
6. **Tiegs and Manton theory** : They established idea of Uniramia, distinct from biramous Crustacea and chelicerates.
7. **Charlotte Manton Theory** : He believed that crustaceans evolved from annelid worms similar to marine polychaetes of today, and that all other arthropods evolved from annelid worms that were more similar to the onychophora.
8. **Symphylan theory** : This theory was proposed by proposed by Calman and Imms in 1936. The symphylans and the hexapods (but not the centipedes) have experienced an anatomical fusion of the second maxillae. This medial fusion of the left and right side appendage has produced a mouthpart called the labium. It is tempting to interpret this structural similarity as evidence of a close evolutionary affinity between Symphyla and Insecta.
9. **Theory on the origin of insects from Myriapods** : Insects have more in common with the myriapods than with any other taxon of the Arthropoda. Insects and myriapods are adapted to a terrestrial lifestyle, exhibit similar embryological development, and share many similarities in the morphology of the head and mouthparts. Most biologists and paleontologists feel that there is sufficient morphological, embryological, and fossil evidence to justify a claim that the basic structural plan of the insect head evolved very early in the myriapod lineage.

## 1.8 EVOLUTION OF WINGS

### ■ Evolution of the insect wing

Part of insect body which could have probably evolved into wings

- i. Outgrowths of pleura (side of thoracic segment) possibly used as gills
- ii. Paranotal lobes (top sclerite of thoracic segment) - seen in some early fossils
- iii. Portions of segmental appendage (leg) Style on sub coxa, possibly used as a gill branch of a basal segment above the spiracle

### ➤ There are 3 major theories regarding evolution of wings in insects

1. The tracheal gill theory
2. Paranotal theory
3. Epicoxal theory

**1. The tracheal gill theory**

According to this theory wings are derived from thoracic tracheal gills which later became adapted to purpose of flight. This view is now no longer acceptable since the development of tracheal gills is very inconsistent. They may develop from tergum, sternum or pleuron at apex of abdomen, on head or even in between the wings. Moreover, one has to presume that the ancestors of insects were positively aquatic – a fact which is not true.

**2. Paranotal theory**

It proposes that wings originated from rigid, lateral projections of thoracic terga that became enlarged, flattened, supplied with a regularized system of veins, and eventually articulated with the thorax to produce flapping flight. However, the paranotal theory suffers from several deficits, including absence of evidence for an articulatory wing hinge characterizing the attachment of paranotal lobes to an associated thorax, thus disallowing flapping flight.

**3. Epicoxal theory**

It speculates that serially homologous protowings originated in semiaquatic insects from small appendages located above the leg bases, known as epicoxal exites, initially for purposes other than aerial flight. Subsequently, protowings developed laterally on thoracic and abdominal segments from these exites, which were initially articulated to the pleurae, a condition different from the initially rigid attachment proposed by the paranotal theory.

## **1.9 DISTINGUISHING FEATURES OF IMPORTANT INSECT ORDERS AND FAMILIES**

**I. Order Lepidoptera (Moths and butterflies)**

**The characteristics which distinguish the order Lepidoptera from other insect orders are**

- The name Lepidoptera means “scale wings.” Body, wings and appendages covered with scales
- Head is hypognathous
- Antennae are of various types, clavate, pectinate, plumose. They also have a Johnston’s organ, on the pedicel
- Compound eyes are well developed
- Mouth parts are siphoning type. Mandibles are vestigial. Long coiled proboscis is formed by galeae of maxillae, labial palpi well developed

- Prothorax in most species is reduced. Mesothorax is large and distinct
- Wings are two pairs, large and covered by scales. Microtrichia are present
- Wings are folded vertically upward in butterflies and these are held roof like in moths at rest
- Abdomen is slender or tubular. The posterior abdominal segments are modified extensively for reproduction. Cerci are absent. Tympanal organs are present at the base of abdomen
- Genitalia : 9<sup>th</sup> and 10<sup>th</sup> segments form telescopic oviopositor
- Larva : The larvae are eruciform with well developed head and mandibles. They have 0 to 10 prolegs, usually 8. Prolegs armed with crochets. The larvae are commonly called caterpillars
- Pupa : The pupae in most species are adecticous and obdect, while they are decticous in others. Pupae of moths are called cocoons and of butterflies called chrysalis

#### Differences between moths and butterflies

| Character                              | Butterflies                                                                                                     | Moths                                                                                                                                                                                                              |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Shape and structure of antennae</b> | Most butterflies have thin slender filamentous antennae which are club shaped at the end ( <b>Rhopalocera</b> ) | Moths have comb-like or feathery antennae, or filamentous and un-clubbed ( <b>Heterocera</b> )                                                                                                                     |
| <b>Wing coupling mechanisms</b>        | Amplexiform of wing coupling mechanism                                                                          | Many moths have a frenulum which is a filament arising from the hind wing and coupling with barbs on the forewing. Some moths have a lobe on the forewing called a jugum that helps in coupling with the hind wing |
| <b>Pupae</b>                           | Most butterflies form an exposed pupa, also known as chrysalis                                                  | The pupa is enclosed in a cocoon or shell                                                                                                                                                                          |

|                                 |                                                                                  |                                                                                                                                                                   |
|---------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Colouration of the wings</b> | Most butterflies have bright colours on their wings                              | Nocturnal moths on the other hand are usually plain brown, grey, white or black and often with obscuring patterns of zigzags or swirls which help camouflage them |
| <b>Structure of the body</b>    | Butterflies possess fine scales and have slender slender and smoother abdomens   | Moths tend to have stout and hairy or furry - looking bodies, and scales on their wings which makes them look more dense and fluffy                               |
| <b>Behavioural differences</b>  | Most butterflies are diurnal except <i>Melanitis</i> sp.                         | Most moths are nocturnal or crepuscular except <i>Utethisia</i> sp.                                                                                               |
| <b>Resting posture</b>          | Butterflies frequently fold their wings above their backs when they are perched  | Moths usually rest with their wings spread out to their sides                                                                                                     |
| <b>Economic importance</b>      | Most butterflies are pollinators in adult stage and weed killers in larval stage | The larval stages feed on cultivated crops and thus become important crop pests                                                                                   |
| <b>Example</b>                  | Blue butterfly                                                                   | Fruit sucking moth                                                                                                                                                |

### ➤ Economically important families

#### 1. Papilionidae (Swallow tail butterflies)

- Iridescent black and strikingly marked with shades of yellow, red green or blue
- Antennae clubbed, fore tibia with pads
- Hind wing with a tail like prolongation which is marginal extension of vein  $M_3$
- Larvae is smooth with a series of fleshy dorsal tubercles
- Pupa is chrysalis with two lateral cephalic projections

Ex : Lemon butterfly, *Papilio demoleus*

**2. Nymphalidae (Brushfooted and Emperor butterflies)**

- Brightly coloured with clubbed antennae
- Forelegs reduced and vestigial, folded on to the thorax
- The tarsi of forelegs are unjointed in males and 4 or 5 segmented in females
- The short tibiae are covered with long hairs hence the name brush footed butterflies
- Larvae with spines and a pair of anal processes directed backwards

Ex : Emperor butterfly, *Nymphalis*

**3. Gelichiidae (Gelichiid moths)**

- Small cryptic coloured moths
- Forewings are narrower than the hind wings
- Apical angle of the hind wing is pointed
- Larvae feed under concealment
- Labial palpi are long and upcurved

Ex : Groundnut leaf miner, *Aproaerema modicella*

**4. Arctiidae (Tiger moths)**

- Body is stout and broad
- Wings are brightly coloured with spots or bands
- Hind wing with two anal veins
- Larvae are densely clothed with long hairs

Ex : Red hairy caterpillar, *Amsacta albistiga*

**5. Noctuidae (Army worms, borers and cut worms)**

- Moths are cryptic and dull coloured
- Insects are nocturnal and attracted to light
- Proboscis is present and labial palp is long and well developed
- Maxillary palpi minute
- Cu<sub>2</sub> absent in both wings
- Larvae with all prolegs bearing crochets except in semiloopers in which first two pairs are wanting
- Pupation takes place in soil

Ex : Tobacco caterpillar, *Spodoptera litura*

#### 6. Saturniidae (Tasar silk moths)

- Very large coloured moths
- Labial palpi is small and frenulum is absent
- The larvae are stout, smooth and possession of scoli (characteristic feature)
- Wings with transparent fenestrae or eye spots
- Proboscis vestigial or absent
- Antennae is pectinate in males and females
- Pupation in silken cocoon

Ex : Muga silk moth, *Antheraea assama*

#### 7. Sphingidae (Hawk moths)

- Large robust flying moths
- Antennae hooked apically
- Proboscis is extremely long and frenulum is well developed
- Larvae with longitudinal and oblique stripes. They possess horn like process on the 8<sup>th</sup> abdominal segment
- Pupation inside cocoon

Ex : Deaths's hawk moth, *Acherontia styx*

#### 8. Hesperidae (Skippers)

- They derive their name from their erratic darting flight
- Small, short, stout, somber coloured butterflies
- Antennae is clavate with curved tip and widely separated at the base
- Hind tibia usually with two pairs of apical spurs
- Larvae with five pairs of prolegs bearing crotchets
- Pupa is attached to leaf from anal end by a silken thread

Ex : Paddy skipper, *Pelopidas mathians*

#### 9. Pyralidae (Snout moths)

- Small delicate moths with labial palpi projecting forward into a snout like structure
- Fore wings are elongate or triangular
- Cu<sub>2</sub> absent in forewing and present in hind wing
- Legs are slender and long
- Tympanum present at the base of the abdomen
- Adult females provided with a tuft of hairs at the caudal extremity

Ex : Indian meal moth, *Plodia interpunctella*

### 10. Lycaenidae (Blue coppers)

- Adults are small and brightly coloured, sometimes with a metallic gloss
- The male's forelegs are reduced in size and lack claws
- Tail like delicate prolongations are seen on the hind wings
- Larvae are often flattened rather than cylindrical, with glands that may produce secretions that attract and subdue ants

Ex : Pomegranate butterfly, *Virachola isocrates*

## II. Coleoptera (Beetles and weevils)

### ➤ Distinguishing characteristics of insect order Coleoptera are

- Coleoptera means "sheath wings," a reference to the hardened forewings which cover the insect's body
- Highly sclerotized endopterygote insect order with leathery elytra, biting and chewing type of mouth parts and compodeiform and eruciform larvae
- Coleoptera constitute the largest and most diverse order of insects on earth, making up about 30% of all animals
- Head is strongly sclerotized pro or hypognathous
- Antennae is 11 segmented and present in a variety of forms
- Compound eyes in a variety of sizes and shapes like acone, eucone and pseudocone
- Prothorax is large and mobile whereas, mesothorax is reduced
- Mouth parts are biting and chewing type. Mandibles are well developed. Legs are variously modified for swimming, running, jumping, walking and fossorial
- Forewings hardened, hind wings are membranous used for flight. Hind wings folded under elytra, with reduced venation
- Genitalia is concealed and retracted into abdomen
- Metamorphosis is holometabolous, larvae generally appear grub-like with a well-defined head capsule and highly sclerotized. Pupa is aedeicous and exarate

Coleoptera is divided into four suborders, Adephaga and Polyphaga, Myxophaga and Archostemata

### ➤ Suborders of Coleoptera

1. **Polyphaga** : It is by far the largest suborder, containing 85 % of the known species, including rove beetles, scarabs, stag beetles, metallic wood-boring beetles, click beetles, fireflies, blister beetles, mealworms, ladybirds, leaf beetles, longhorn beetles,



and weevils. Many are phytophagous.

2. **Adephaga** : It includes ground beetles, tiger beetles, predacious diving beetles, and whirligig beetles; most adephagans are predacious.
3. **Myxophaga** : It is a small suborder, members are small or minute, and associated with hygropetric habitats, drift material, or interstitial habitats among sand grains.
4. **Archostemata** : It contains several families of beetles, most associated with wood and these are not known to occur in India so far.

➤ **Economically important families**

1. **Bruchidae (Seed beetles)**

- Adults are free living and larvae are internal feeders of legume seeds
- They are small and stout, body is covered with small setae or scales and are pale grey or brown in colour
- Head hypognathous and snout like proboscis
- Prothorax prominent somewhat triangular, notum is greatly narrowed anteriorly
- Antennae is clavate, serrate or pectinate
- Elytra is striated, short and do not cover the tip of the abdomen (pygidium)
- Legs are short, hind femur thickened and toothed beneath, tarsal formulae, 5-5 - 5

Ex: Pulse beetle, *Callosobruchus maculatus*

2. **Chrysomelidae (Flea beetles)**

- Adults are oval and convex, with metallic colouration
- Antennae widely separated at the base
- Prothorax is laterally marginated and narrow
- Legs are well adapted for running and jumping
- Elytra covers entire body, pygidium not exposed beyond elytra
- Third tarsal segment is bilobed

Ex: Rice hispa, *Dicladispa armigera*

3. **Curculionidae (Weevils)**

- Head modified into long rostrum. Mouth parts at the tip of the rostrum
- Rostrum is well developed in females and used to bore hole for placing the eggs
- Labrum is absent, palps are reduced and mandibles are lacking or reduced

- Antennae is clubbed, geniculate or clavate
- Larvae apodous and phytophagous

Ex: Red palm weevil, *Rhynchophorus ferrugineus*

#### 4. Scarabaeidae (Dung beetles)

- Small to large, oval or convex body
- Head and prothorax with horns
- Antennae 8 - 10 segmented
- Elytra not usually completely covering the abdomen. Exposed area is called pygidium
- Hind tibia with spur
- Tarsus 5 segmented, front tibia dilated and toothed
- Larvae scarabaeiform, saprophytic or phytophagous

Ex: Coconut rhinoceros beetle, *Oryctes rhinoceros*

#### 5. Cerambycidae (Long horned beetles)

- Body long and cylindrical with attractive colouration
- Prothorax is narrow or as wide as mesothorax, usually spined or tuberculate
- Stidulatory organs on the hind margin of prothorax
- Antennae very long at least 2/3 of the body length
- Tarsi 5 segmented, tibia with 2 spurs
- Grubs are apodous, elongate, cylindrical, whitish and bore into woods

Ex: Mango stem borer, *Batocera rufomaculata*

#### 6. Coccinellidae (Lady bird beetle)

- Adults are small, oval or spherical convex, brightly covered with coloured spots
- Head concealed in pronotum
- Tarsi 4 segmented and 3<sup>rd</sup> segment concealed in the deeply bilobed second segment
- Antennae short, clubbed 3 to 6 segmented
- Larvae campodeiform usually covered with minute tubercles or spines
- Both adults and grubs are predaceous on soft bodied insects and mites

Ex: Lady bird beetle, *Coccinella septempunctata*

#### 7. Bostrychidae (Grain / furniture / bamboo borers)

- Small to large, cylindrical body, black to brown in colour
- Head concealed in hood

- Head is hypognathous
- Antennae clubbed
- Trochanter joined obliquely to femur
- Larvae with small head but large thorax and are borers

Ex : Lesser grain borer, *Rhyzopertha dominica*

#### 8. Carabidae (Ground beetles)

- They live under stones, ground and bark
- Oval and broad, dorsoventrally flattened beetles with metallic, bright dark coloration
- The elytra are firmly attached together and wings may be atrophied
- The legs are slender and adapted well for running and digging
- Adults and larvae are carnivorous

Ex : Egyptian predator beetle, *Anthia sexguttata*

#### 9. Elateridae (Click beetle or wireworms)

- The adults are typically nocturnal and phytophagous
- Tibia with 2 spurs, Antennae is 11 segmented pectinate inserted near eyes
- A spine on the prosternum is snapped into a corresponding notch on the mesosternum, producing a violent “click”
- Click beetle larvae, called wireworms, are usually saprophagous and phytophagous
- A few species are bioluminescent (in both larvae and adult forms) example *Pyrophorus*

Ex : Wheat wireworm, *Agriotes mancus*

#### 10. Dermestidae (Carpet / khapra beetles)

- Size range from 1 – 12 mm.
- Adults are round oval shaped body covered with scales or setae
- Antennae is clubbed and fit into deep grooves
- Hind femora fit into recesses of the coxa
- Larvae are scarabaeiform and covered with setae

Ex : Khapra beetle, *Trogoderma granarium*

### III. Diptera (Mosquitoes, flies, and midges)

- **The characteristics which distinguish the order Diptera from other insect orders are**
- Endopterygote insect order with a pair of forewings, extremely reduced thread like hind wings (halters), suctorial proboscis and apodous larvae (maggots)
- Head is prognathous, eyes are large and holoptic in males and dichoptic in females. Ocelli are 3, arranged in triangle
  - Antennae in Nematocera is filiform in females and plumose in males, Brachycera it is stylet and in Cyclorrhapa it is aristate type
  - Mouth parts are piercing and sucking type in blood sucking insects and sponging in non blood sucking Cyclorrhapa
  - Meso thorax is well developed, pro and meta thorax greatly reduced
  - Only one pair of forewings, hind wings are extremely reduced (halters)
  - Legs are well developed for clinging, tarsi 5 segmented, paired claws, with empodium and pulvilli
  - Undergo complete metamorphosis- larvae apodous, pupa is either free or enclosed in puparium
- Order Diptera is divided into 3 sub orders namely Nematocera, Brachycera and Cyclorrhapa

➤ **Economically important families**

**1. Culicidae (Mosquitoes)**

- Body slender, long with out ocelli
- Antennae plumose in males, pilose in females
- Wings are fringed, scales along veins and posterior margin
- Larvae are aquatic with metaneustic arrangement of spiracles
- Members are vectors of various diseases. Only females are blood suckers, while males are nectar feeders

Ex : *Aedes aegypti*

**2. Cecidomyidae (Gall flies)**

- Minute delicate flies with long moniliform antennae and with conspicuous whorls of hairs

- Wing venation is reduced with few longitudinal veins and with out cross veins
- Tibia with out spurs
- Last larval stage most of the species possess a sternal spatula or breast bone on the ventral side of the prothorax

Ex : Rice gall midge, *Orseolia oryzae*

### 3. Tachinidae (Tachnid flies)

- Small to medium sized black or brown flies
- Adults with pteropleural and hypopleural bristles
- Abdomen clothed with long conspicuous marginal, apical and dorsal bristles
- The larvae are internal parasitoids of insects especailly Lepidoptera
- Pupates outside the body of the host

Ex : *Sturmia bimaculata*

### 4. Agromyzidae (Leaf miner flies)

- Minute black or yellow flies
- Vibrissae present, subcosta vestigial
- Fore femur with ventral spine or bristle
- Larvae are leaf miners, tunnel into stems and roots
- They pupates in larval mine and female with an ovosac

Ex : Red gram pod fly, *Melanagromyza obtusa*

### 5. Syrphidae (Hoverflies)

- Adults are often seen hovering or nectaring at flowers, hence called hover flies
- Wasp or bees like, brightly coloured with yellow stripes or bands
- Larvae are insectivorous and prey on aphids, thrips, and other plant-sucking insects
- Hoverflies are distinguished from other flies by a spurious vein, located parallel to the fourth longitudinal wing vein

Ex : *Syrphus* sp.

### 6. Muscidae (True flies)

- Mouth parts sponging in house flies and sucking in others
- Antennae 3 - segmented, aristate, Arista usually plumose for the entire length
- Frontal suture present, calypters well developed

- Vein Rs 2 - branched and Vein 2A short and not reaching wing margin
- Larvae mainly breed in decaying plant material or manure
- Adults of many species are passive vectors of diseases

Ex : House fly, *Musca domestica*

#### 7. Tephritidae (Fruit flies)

- Small to medium sized insects usually with spots or bands on wings
- The subcoasta bends apically forward at almost aright angle and then fades out
- Female with well developed horny ovipositor
- Male with long flexible coiled aedagus
- Middle tarsus with spurs
- Larvae feed on fruits or bore into stems or flower heads

Ex : Mediterranean fruit fly, *Ceratitis capitata*

#### 8. Tabanidae (Horse flies)

- They have stout body with large heads, the eyes are golden green and purple marks
- Eyes are holoptic in males and dichoptic in females
- They are known to be extremely noisy during flight
- Antennae 3 segmented, segment 3 annulate, arista absent
- Females are blood sucking and males are nectar feeding

Ex : *Tabanus speciosus*

#### 9. Anthomyiidae (Shoot flies)

- Small to medium dark coloured flies
- Sixth vein ( $Cu_2 + 2A$ ) usually reaching the wing margin
- Under surface of the scutellum fine erect hairs and more than one sternopleural bristle
- Larvae are cylindrical and truncate posteriorly
- Larvae are phytophagous and saprophagous

Ex : Sorghum shoot fly, *Atherigona soccata*

#### 10. Asilidae (Robber flies)

- Long bristle flies with horny piercing proboscis
- Strong prehensile fore legs for catching and piercing the prey

- Tuft of hairs forming bearded face and protruding eyes (characteristic feature)
- The legs end in a bristle like empodium and large pulvilli
- Larvae are cylindrical with small conical head
- Larvae are predaceous or scavengers
- Pupa with girdles of spines dorsally on head and trunk

Ex : *Hyperechia* sp.

#### IV. Hymenoptera (Sawflies, wasps, ants and bees)

➤ The characteristics which distinguish the order Hymenoptera from other insect orders are

- Many species have highly developed social life
- Head is hypognathous
- Antennae is geniculate, clavate, filiform or pectinate
- Eyes are well developed except in some ants
- Mouthparts are biting and chewing type in Symphyta, lapping and sucking in bees
- Mesothorax is large. First abdominal segment is fused with meta notum forming propodeum. Rest of the abdomen forms gaster or metasoma. First segment is modified into petiole
- Forewings are large and hind wings are small. During flight forewings are interlocked with hind wings with a row of hooks called hamuli
- Legs are variously modified. Trochanter along with trochantellus present
- Ovipositor is well developed, secondarily modified for sawing, boring, stinging and piercing
- Metamorphosis is holometabolous. Larvae is apodous with well developed head, pupae exarate and pupates in cocoon

Order Hymenoptera is divided into two sub orders

Symphyta – Primitive Hymenoptera (sawflies)

Apocrita – Highly evolved Hymenoptera (wasps, ants and bees)

##### 1. Tenthredinidae (True sawflies)

- Wasp like small to medium sized, brightly coloured insects
- Ovipositor with serrated flat plates

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- Fore tibia with 2 apical spurs
- Larvae caterpillar like and feed on flowers, leaves of vegetables
- Larvae with 6 to 8 pairs of prolegs without crochets
- Pupation takes place in an elongated silken cocoon or earthen cell

Ex: Mustard sawfly, *Athalia lugens proxima*

#### 2. Ichneumonidae (Ichneumon flies)

- These are important parasitoids of larvae and pupae of Coleoptera, Hymenoptera and Lepidoptera
- Antennae is long with typically 16 or more segments
- Ovipositor is long and extruded permanently
- Long antennae, presence of trochantellus on hind femur
- Absence of anal lobe on hindwing
- Distinct pterostigma and narrow costal cell on forewing
- Two distinct recurrent cross veins

Ex: *Isotima javensis*

#### 3. Braconidae (Braconids)

- Most braconids are primary parasitoids (both external and internal) on other insects
- Very small stout bodied insects
- Ovipositor is long and many species are egg-larval parasitoids
- Only one recurrent vein, cross vein 2m- Cu is absent in the fore wing
- Pupation within cocoon inside or outside body of host

Ex: *Bracon hebetor*

#### 4. Chalcididae (Chalcid wasps)

- Minute to small metallic coloured insects
- Primary or secondary parasites of eggs, larvae and pupae of insects
- Hind femur stout and swollen with rows of short teeth (characteristic feature)
- Wings are not folded longitudinally at rest
- Ovipositor short and straight

Ex: *Brachymeria* sp.

#### 5. Encyrtidae

- These are small parasitic wasps
- The cerci forwards on the metasoma



- Greatly enlarged mesopleuron with anteriorly-positioned mesocoxae
- Some species exhibit polyembryony
- These insects are parasites of aphids, whiteflies and scales insects

Ex : *Anicetus communis*

#### 6. Eulopidae

- These are small insects and are parasitic of eggs, larvae and pupae of insects
- Tarsi 4 or 5 segmented
- Antennae is pectinate with 2-4 funicle segments and at most ten antennomeres
- Only 4 tarsomeres on each leg
- Forewings are narrow and pubescence not in rows or lines
- A small, straight protibial spur is present

Ex : *Trichospilus pupivora*

#### 7. Trichogrammatidae

- These are very minute insects with three segmented tarsi
- Fore wings are board with rows of microscopic hairs
- These parasitize the eggs of large number of insects especillay Lepidoptera
- They are not strong fliers and passive fliers (move along with the wind)
- Their forewings are typically some what stubby and paddle-shaped, with a long fringe of hinged setae around the outer margin to increase the surface area during the downstroke

Ex : *Trichogramma chilonis*

#### 8. Elasmidae

- These are primary or hyper-parasitic on a variety of Lepidopterans and Hymenopterans
- These are small brown or black wasps with compressed hind legs
- Greatly enlarged hind coxae and the wavy lines or diamond-shaped patterns of setae on the hind tibiae
- The elongated, overhanging flange of the scutellum is present some times

Ex : *Elasmus brevicornis*

#### 9. Vespidae (Social wasps)

- Red or yellow body with black markings
- Antennae 12 segments in females and 13 segments in males

- Long slender petiole and fore wings possess a very long first discoid cell
- Submarginal cells 3 in forewing, hind wings with out anal lobe
- Trochanter undivided and no trochantellus
- Abdomen is sessile and modified into terminal ovipositor or sting

Ex : *Vespa cincta*

#### 10. Apidae (Honey bees)

- Social insects with 3 castes, queen, worker and drones
- Mouth parts chewing and lapping type, labrum broader than long
- Three submarginal cells in fore wing, the third oblique. One radial cell
- Three pairs of legs modified for different functions
- Hind tibia with out spurs, fore and mid tibia with apical spines
- Ovipositor is well developed and modified into sting

Ex : *Apis dorsata*

#### 11. Bethyridae

- Small to medium-sized wasps, dark coloured with an elongate head
- These are parasitic on larvae of Lepidoptera and Coleoptera
- Slightly elbowed, 12 or 13 segmented antennae
- The wing venation is reduced, and the hind wing has a jugal lobe
- The females of many species are apterous and ant-like, and a few will sting
- The larvae are external parasites, pupates in a silken cocoon

Ex : *Nephantis serinopa*

### V. Hemiptera (Bugs, plant lice and scale insects)

➤ The characteristics which distinguish the order Hemiptera from other insect orders are

- Head is hypognathous
- Tentorium is absent in Heteroptera and reduced in Homoptera
- Mouth parts are piercing and sucking type
- Prothorax is large and free, with large pronotum
- Forewings are modified into hemelytra and hind wings are membranous in heteroptera

- Fore wings are uniform and hind wings are membranous in Homoptera
- Legs are variously modified, tarsi 2-3 segmented in Heteroptera and 1-3 segmented in Homoptera
- Sound producing organs are well developed

Order Hemiptera is classified into two sub orders namely Heteroptera and Homoptera.

#### Differences between Heteroptera and Homoptera

| S.No. | Heteroptera                                    | Homoptera                                            |
|-------|------------------------------------------------|------------------------------------------------------|
| 1     | Head is porrect                                | Head is deflexed                                     |
| 2     | Gula is sclerotized and large                  | Gula is small and membranous                         |
| 3     | Ponotum is large                               | Pronotum is small                                    |
| 4     | Base of rostrum has no contact with fore coxae | Rostrum extends between fore coxae                   |
| 5     | Tarsi is 3 segmented                           | Tarsi is 1-3 segmented                               |
| 6     | Wing are folded, flat over the abdomen         | Wings are sloping outer sides of the abdomen         |
| 7     | Forewings are hemielytra<br>Ex : Bugs          | Forewings are uniformly thick or thin<br>Ex : Aphids |

#### ➤ Economically important families of Heteroptera

##### 1. Reduviidae (Assassin bugs)

- Brown to black, medium sized insects
- Rostrum 3 segmented, curved and its tip fits in a posterior groove
- Fore legs bear adhesive pads on tibia
- Metathoracic scent glands absent
- Most of these are predacious and some are blood sucking

Ex : *Rhodnius prolixus*

##### 2. Lagaeidae (Chinch bugs)

- Small, brightly coloured with red, black or white spots or bands
- Antennae and rostrum 4 segmented

- Legs possess rotatory coxae and tarsi 3 segmented
  - Wings are characterized by 4 or 5 simple veins in the membrane of the hemielytra
- Ex : *Oxycarenus* sp.

**3. Pentatomidae (Stink bugs)**

- Brightly coloured, medium size and shield like shape, produce disagreeable odour
- Antennae 4 or 5 segmented and base is concealed by lateral margin of the head
- Scutellum triangular and extends posterior and covers the wings entirely
- Hemielytra well developed with 5-12 veins
- Mostly phytophagous and some are predacious

Ex : Green plant bug, *Nezara viridula*

**4. Pyrrhocoridae (Red bugs)**

- Brightly coloured with red or black markings, elongate or oval in shape
- Antennae 4 segmented and rostrum 4 segmented
- Ocelli absent
- Membrane of hemielytra with 5 unbranched veins
- Coxa is rotatory and tarsi 3 segmented

Ex : Red cotton bug, *Dysdercus cingulatus*

**5. Coreidae (Leaf footed bugs)**

- Dull coloured brownish bugs
- Body oval to elongate with narrow head
- Antennae 4 segmented situated well on the sides of head
- Both hind femora and tibia have conspicuous enlargement or leaf like hence the name leaf footed bugs
- Produce pungent smell
- Membrane of hemielytra with 5 unbranched veins

Ex : Rice gundhi bug, *Leptocorisa varicornis*

**6. Cicadellidae (Leaf hoppers or jassids)**

- Slender insects with tapering posterior, wedge shaped. They run sideways
- Pronotum never prolonged backwards

- Hind tibia with two or more rows of spines
- Ovipositor long, sharp and needle like
- Vectors of viral diseases

Ex : Green leaf hopper, *Nephotettix virescens*

#### 7. Delphacidae (Plant hoppers)

- Antennae with terminal arista
- Tegula usually present, ovipositor well developed
- Alary polymorphism is very common, winged, wingless and brachypterous forms occur in same species
- Hind tibia with large mobile apical spur
- Middle coxae elongate and hind coxae immobile

Ex : Brown plant hopper, *Nilaparvata lugens*

#### 8. Aphididae (Aphids, plant lice)

- Small soft bodied, pear shaped insects with a pair of cornicles on 5 or 6 the abdominal segment
- Antennae long, tapering distally
- Polymorphic alate forms with 2 pairs of transparent membranous wings
- Tarsus 3 segmented with a pair of claws
- They excrete honey due to which ants are attracted

Ex : Groundnut aphid, *Aphis croccivora*

#### 9. Aleurodidae (Whiteflies)

- Minute insects, wings and body dusted with characteristic mealy powder
- Antennae well developed with 7 segments
- Presence of vasiform orifice in the last abdominal segment
- Tarsi 2 segmented terminating into pad like empodium or spine in between the claws
- Oviparous and eggs are stalked
- First instar nymph is mobile and next two instars are immobile
- The adult emerges by means of 'T' shaped rupture of the dorsal wall of the pupa

Ex : Cotton whitefly, *Bemisia tabaci*

**10. Coccidae (Mealybugs, scale insects)**

- Minute, inconspicuous and highly specialized insects
- Body is covered with waxy or powdery coating
- Females apterous, degenerate larviform, scale like with functional mouth parts
- Males are active, first pair of wings well developed, second pair reduced to halteres
- Tarsi 1 segmented with a single claw
- Reproduction bisexual or parthenogenesis

Ex: Coffee green scale, *Coccus viridis*

### **1.10 DNA BARCODING AND ITS APPLICATIONS IN ENTOMOLOGY**

DNA barcoding is a technique for identifying organisms based on a short, standardized fragment of genomic DNA. The standardized sequence region is called a DNA barcode because it is like a barcode tag for each taxon.

In 2003 Hebert *et al.* proposed a technique using a primer set to amplify a 648-base pair (bp) region of the mitochondrial cytochrome-*c* oxidase subunit 1 (COI) gene to ensure rapid and accurate identification of a broad range of biological specimens. They named this technique “DNA barcoding”. Then, the Barcode of Life project was proposed to promote DNA barcoding as a global standard for sequence-based identification of eukaryotes. In 2004, this project was formally initiated by the establishment of the Consortium for the Barcode of Life (CBOL), which aims to develop a standard protocol for DNA barcoding and to construct a comprehensive DNA barcode library.

This technique has attracted attention from taxonomists, ecologists, conservation biologists, agriculturists, plant-quarantine officers and others, and the number of studies using the DNA barcode has rapidly increased. The extreme diversity of insects and their economical, epidemiological and agricultural importance have made this group a major target of DNA barcoding.

Species identification through barcoding is usually achieved by the retrieval of a short DNA sequence – the ‘barcode’ – from a standard part of the genome (i.e. a specific gene region) from the specimen under investigation. The barcode sequence from each unknown specimen is then compared with a library of reference barcode sequences derived from individuals of known identity. A specimen is identified if its sequence closely matches one in the barcode library. Otherwise, the new record can lead to a novel barcode sequence for a given species (i.e. a new haplotype

or geographical variant), or it can suggest the existence of a newly encountered species.

Various gene regions have been employed for species-level biosystematics, however, DNA barcoding advocates the adoption of a 'global standard', and a 650-base fragment of the 5' end of the mitochondrial gene cytochrome c oxidase I (COI, *cox1*) has gained designation as the barcode region for animals. This fragment size has been selected so that a reliable sequence read can be obtained by a single sequence pass in conventional cycle sequencing platforms.

## ■ APPLICATIONS OF DNA BARCODING FOR ENTOMOLOGY

DNA barcoding provides many benefits to both basic and applied Entomology.

Identifications using molecular data can help elucidate the relationships of morphologically variable individuals of the same species, such as individuals in different developmental stages, castes in social animals and sexually dimorphic individuals. Insects, especially those of holometabolous orders, are extremely variable, and numerous attempts have been made to associate their life stages using molecular markers. In addition to the features of typical non-barcode molecular markers, the advantages of DNA barcoding include primer universality, the accumulation of information on a wide range of taxonomic groups, and its association with taxonomy. These advantages may aid the study of ecologically interesting insect phenomena, such as host plant alternation among aphids, extreme sexual dimorphism and heterotrophic heteronomy of Strepsiptera.

### • Cryptic host specificity

DNA barcoding helps to identify species interactions. Host specificity of parasitic insects can be evaluated using DNA barcodes. Ex: Seventeen (17) morphologically discriminated species candidates and another 15 cryptic species candidates of caterpillar parasitoid flies (Tachinidae) are identified using DNA barcodes. Extraordinary diversity of tachinid flies and parasitic wasps are identified using DNA barcodes.

Actual host utilization of fig-associated *Sycophila* wasps (Hymenoptera: Eurytomidae) using both barcode and non-barcode sequences is determined. Plant DNA barcode data make it possible to identify host plants from plant tissues on insect bodies and from digested materials.

Host specificity of Australian leaf beetles (Coleoptera: Chrysomelidae) and their associations with plants is identified using the DNA barcoding approach.

The future accumulation of reference DNA barcodes for entire biota will make DNA barcoding a useful tool for studying host specificity and diversification processes in nature.

- **Trophic relationships**

Numerous studies have been conducted to reveal the trophic relationships between predator and prey or herbivore and plant by detecting prey or host DNA from the gut contents or faeces of the predators or herbivores using specific primers or antibodies. These studies have shown that a molecular approach can reveal trophic interactions in nature.

To estimate the composition of the bat's prey, quantitative analysis of DNA barcodes from guano of the Eastern red bat *Lasiurus borealis* revealed that the bats prey mostly on Lepidoptera except for Arctiidae, even though many of the prey species have a tympanal organ, which was believed to be an effective defense mechanism against bat attack. This result also suggests the effectiveness of multiple putative defense mechanisms in Arctiinae, such as ultrasonic jamming.

DNA barcode enables researchers to trace not only trophic links, but also changes in diet according to season or the developmental stage of an insect. Quantitative analyses such as pyrosequencing may make trophic studies using the DNA barcode more comprehensive, quicker and easier.

- **Applied Entomology and commercial use**

DNA barcoding has become a standard identification protocol for various organisms. One of the initial major targets of DNA barcoding is insects.

A simple and rapid species identification system is necessary for commercial, agricultural, environmental, conservational and epidemiological uses. DNA barcode can detect illegal trade of endangered or protected insects, such as birdwing butterfly used for ornaments and some stag beetles kept as pets.

For agriculture and the conservation biology, the rapid detection of serious pests and/or invasive species could prevent their establishment. Many molecular-based methods for identifying various organisms using various tools and target molecules have been introduced. For epidemiological purposes, rapid identification methods would facilitate the monitoring of disease vectors such as mosquitoes. DNA barcoding has the potential to become a standard tool for species identification in these fields.

Invasive pests are the most serious threat to biodiversity, and their rapid and accurate identification is indispensable in terms of biosecurity. For this purpose, global coverage in the DNA barcode library is of great value. DNA barcoding-based identification is better compared to previous molecular-based methods and, useful for monitoring pests and detecting unpredictable species. Outbreaks of invasive leaf miner pests (Diptera: Agromyzidae) in the Philippines revealed the presence of three species of *Liriomyza*.

DNA barcoding also helps to identify specimens in various developmental stages,



which are difficult or impossible to identify morphologically due to a lack of reliable characteristics. Rapid identification of the larvae of pest species is very important for pest control.

DNA barcoding is also a useful tool for searching for candidates of biological control agents and evaluating their potential risks. The importance of biological control agents that predate upon or infest pests in nature has increased due to the expansion of international commerce, which has resulted in an increased chance of invasion by non-native pests. However, searching and screening for, and evaluating the risk of, such agents require long-term feeding experiments. Hence, using DNA barcoding to identify agents based on their gut contents would make this process more efficient.

Combining rapid identification using DNA barcodes and adequate knowledge of fundamental ecology of hematophagous-vector arthropods would make it possible to prevent or minimize the epidemiologic risk of vector-borne pathogens such as malaria, trypanosoma and many viruses.

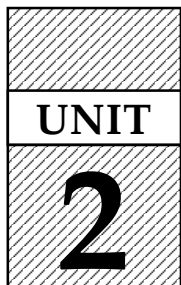
DNA barcoding can also help elucidate the basic ecology (e.g. habit and diet of larva, verification of male and female adults) of vector insects. DNA barcodes from blood meals in the midguts of vectors have revealed complex interactions between vectors and their vertebrate hosts.

The universality of PCR primers and databases make the barcode a more powerful tool than other molecular methods. The establishment of reference barcode libraries for each field is necessary. International Barcode for life (IBOL) is planning to barcode a total of 25,000 species, including aphids, thrips, true fruit flies, scale insects, sawflies and gall wasps.

DNA barcoding projects are strongly related to other biodiversity and genetic database projects. Together with the identification support system, DNA barcode will be a new keyword to explore biodiversity and will serve as a bridge between research in the fields of biodiversity and genomics.

Some taxonomists are concerned that DNA barcoding will compete with traditional taxonomic studies. However, it was emphasize that DNA barcoding is inseparably linked to taxonomy, a powerful tool that complements taxonomic studies. The integration of various types of data, such as morphological, ecological, physiological and molecular data, including DNA barcodes, will improve species discovery and description processes. This integrative approach will be strengthened by various biodiversity databases.





# Morphology

---

## 2.1 BODY WALL

### ■ INTEGUMENT

It is the outermost layer of the insect

It is divided into 2 parts. They are

- I. Epidermis
- II. Cuticle

#### I. Epidermis

The epidermis is the outer layer of the insect. It is one cell thick (unicellular). It is commonly called as hypodermis and it lies below the cuticle. It secretes cuticle.

The epidermal cells have rough endoplasmic reticulum and Golgi complexes and pigment granules. The adjacent epidermal cells are held with one another by means of cytoplasmic process, the desmosomes.

All epidermal cells are glandular they secrete cuticle and the enzymes concerned in its production and its digestion at the time of moulting. Some of the cells are variously modified to form sense organs (chemo- tacto, hygro and photo receptors). Each dermal gland is formed by a group of three epidermal cells, the median cell constituting the body of the gland known as Trichogen cell, while the remaining cells constitute the duct of the gland known as tormogen cells.

They also have peristigmatic glands responsible for the hydrofuge properties of the cuticle surrounding the spiracles which prevent the entry of water into the tracheal system. The oenocytes of the blood are produced from epidermal cells which are involved in the intermediary metabolism

#### II. Cuticle

It is secreted by epidermis. It covers the whole outside body as well as lining of foregut, hindgut and trachea.

It is divided into 2 parts

- a. Inner region – Procuticle (chitinous)
- b. Outer region – Epicuticle (non chitinous)

**a. Procuticle**

It is thicker layer and contains chitin proteins and other substances. Chitin is the main constituent of the procuticle comprising of 20-50% of its dry weight. It also contains special protein called resilin which is present at the joints of wings, mouth parts and legs for articulation.

It has two parts

- i) Exocuticle - Outer part hard and rigid (tanned or sclerotized)
- ii) Endocuticle - Inner undifferentiated part

Between the two layers there is a region of hardened but not fully darkened layer known as mesocuticle

**b. Epicuticle**

It is very thin layer (0.03 to 0.4 microns) and chitin is absent in this layer. During the development of the cuticle special glands in the epidermis produce a waxy material which in dissolved state is carried through the pore canals and deposited over the protein epicuticle.

The epicuticle consists of 4 layers. They are

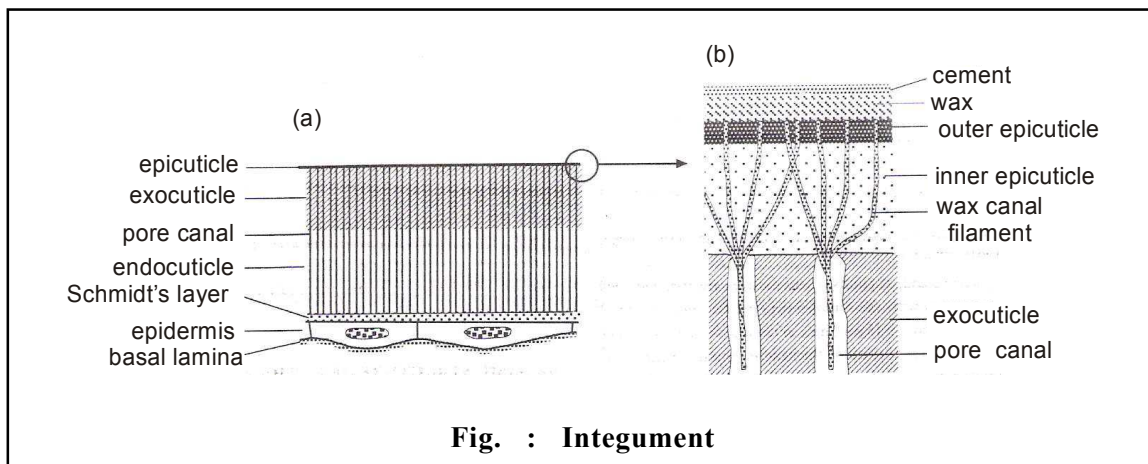
- i. Cement layer
- ii. Wax layer
- iii. Poly phenol layer
- iv. Inner cuticulin layer

During the process of ecdysis special cells of epidermis secrete cement layer which is deposited over the wax layer.

- i. Cement layer :** It is a very thin layer outside of the wax layer. It is secreted by the dermal glands or so called Verson's gland in Lepidoptera. It consists of muco poly saccharides which are closely associated with lipids. It absorbs mobile lipid and serves as reservoir of lipids. The main function is to prevent water loss from the body. It is absent in honey bees.
- ii. Wax layer :** It contains wax molecules and 0.25 microns thick. It consist of long chain hydrocarbons and esters of the both fatty acids and alcohol. It serves as a water proof layer of the integument, as water molecules can not pass through closely packed wax molecules.
- iii. Poly phenol layer :** This layer is rich in various polyphenols. The poly phenols are transported from the epidermis cells through the pore canals and accumulate on outer surface of the cuticulin layer.
- iv. Cuticulin layer :** It consist of lipoproteins and cuticulin. It serves as a permeability and growth barrier. It also determines the surface properties of the integument.

### III. Basement membrane

It is about 0.5 micron thick. The epidermal cells stand on basement membrane. The epidermal cells are anchored to the basement membrane by hemidesmosomes. It is formed from the degenerate epidermal cells. It separates epidermis from the hemocoel. They contain fibrous proteins and glyco proteins. The basement membrane forms a continuous sheet beneath the epidermis and at points where muscle are attached.



**Fig. : Integument**

#### ➤ Functions of cuticle

1. Cuticle acts as exo skeleton providing support to the body and its organs
2. It imparts shape to the body
3. Muscles are attached to the cuticle to facilitate various types of body movements
4. Cuticle is invaginated to provide internal support and muscle attachment
5. Wing movements are possible only because of the presence of hard cuticular flight sclerites in thoracic region
6. The epicuticle wax layer provides a mechanism to conserve water in the terrestrial insects
7. Secretions over cuticular surface in some insects are bactericidal and protect insects from surface infection
8. The intima of fore and hind guts protects epithelium
9. Various parts of cuticle are modified to form sense organs
10. Certain pigments of cuticle imparts colours to insects

➤ **External appendages of integument**

These are 2 types

Non cellular and cellular

1. Non - cellular outgrowths : These include spines, ridges, microtrichia that lack basic articular characteristics
2. Cellular outgrowths : These are classified as unicellular and multicellular appendages

**Unicellular outgrowths** : These outgrowths of the body are termed as setae (macrotrichia). They are of great taxonomic importance as their distribution differs from species to species.

A setae are formed by a single usually large epidermal cell called, trichogen cell. The setae is attached by means of a small setal membrane which is produced by a second epidermal cell called, tormogen cell.

➤ **The setae are of various types**

- a. **Clothing hairs** : These cover the entire body and appendages as found in honey bees.
- b. **Glandular hairs** : These occur around the opening of various epidermal glands and can be seen in few Lepidopteron larvae.
- c. **Sensory setae** : These constitute various mechano and chemo receptors and occur on the antennae, mouth parts, legs and various regions of the body.
- d. **Scales** : These structures are highly modified clothing hairs and are small, flat and scale like. They cover the wings of all adult Lepidopteran insects.
- e. **Bristles** : They are stiff and stout and are present in Tachinidae.

**Multicellular outgrowths** : These appendages are hollow outgrowths of the integument and are lined with epidermal cells. Ex: Spines. These are present on hind tibia of certain Orthoptera or as tubercles that carry a fine branch of trachea and a fine nerve fibre.

## 2.2 BODY REGIONS AND SEGMENTATION

➤ **Insect body regions**

The differentiation of insect body into functional regions or tagmata is called tagmosis. Insect body is divided into 3 parts. They are

1. Head
2. Thorax and
3. Abdomen

1. **Head** : The head bears mouth parts, compound eyes, simple eyes and a pair of antennae. The head is connected to the thorax by a flexible neck or cervix.
2. **Thorax** : The thorax comprises three basic segments named prothorax, mesothorax and metathorax. Each of the three thoracic segments bears a pair of legs in most immature forms and nearly all adult insects. Mesothorax and metathorax are together known as pterothorax, each bearing a pair of wings in pterygota.
3. **Abdomen** : The abdomen consist of varying number of segments with out legs. In most of the insects the primitive number of abdominal segments are 11 and the terminal segment, the periproct or telson bears the anus. The 8<sup>th</sup> or 9<sup>th</sup> or both abdominal segments consist of genital organs.

## Head

Insect head is composite structure formed by the fusion of metameres

The head is made up of 6 segments. They are

1. Preantennary segment bearing protocerebrum
2. Antennary segment bearing the antennae and the deutocerebral ganglia
3. The intercalary segment bearing trito cerebrum
4. The mandibular segment bearing the mandibles
5. The maxillary segment bearing the maxillae
6. Labial segment bearing sub oesophageal ganglion

The endoskeleton of the head is known as tentorium. It consists of 3 pairs of cuticular invaginations called as anterior tentorial arms, posterior tentorial arms and dorsal tentorial arms. The anterior tentorial arms arise from anterior tentorial pits in the sub genal or epistomal suture and posterior tentorial arms arise from posterior tentorial pits in the lower ends of the post occipital suture. The posterior tentorial arms are united to form a structure called as tentorial bridge. The tentorium serves to provide attachment to the ventral muscles of the mouth parts and also support the lower end of the cranial walls. The antennal muscles also arise from the tentorium

## 2.3 SCLERITES AND SUTURES

### Sclerites

These represent simply, the inter sutural areas. The common sclerites found in insect head are

- |               |                    |
|---------------|--------------------|
| • The Labrum  | • The Clypeus      |
| • The Frons   | • The Epicranium   |
| • The Occiput | • The Post occiput |

- The Genae and subgenal areas
- The Occular sclerites

**The Labrum :** It is also known as upper lip in mandibulate insects. It is freely attached to lower margin of the clypeus by the clypeolabral suture. In fluid feeding insects it is variously modified. It is internally lined with the gustatory receptors and can be moved upwards and down wards. The labrum is innervated by compressor labral, the anterior labral and posterior labral muscles.

**The Clypeus :** This sclerite is demarcated by the clypeolabral and clypeo frontal sutures from the anterior and posterior sides. In some insects it is divided into two, posterior part known as post cypeus and anterior part called as anteclypeus by a transverse suture. The post clypeus modified into a convex process known as giglimus of the mandible.

**The Frons :** It extends from anterior clypeo frontal suture to the posterior frontal sutures. The frons represents the typically an upper facial region of the head.

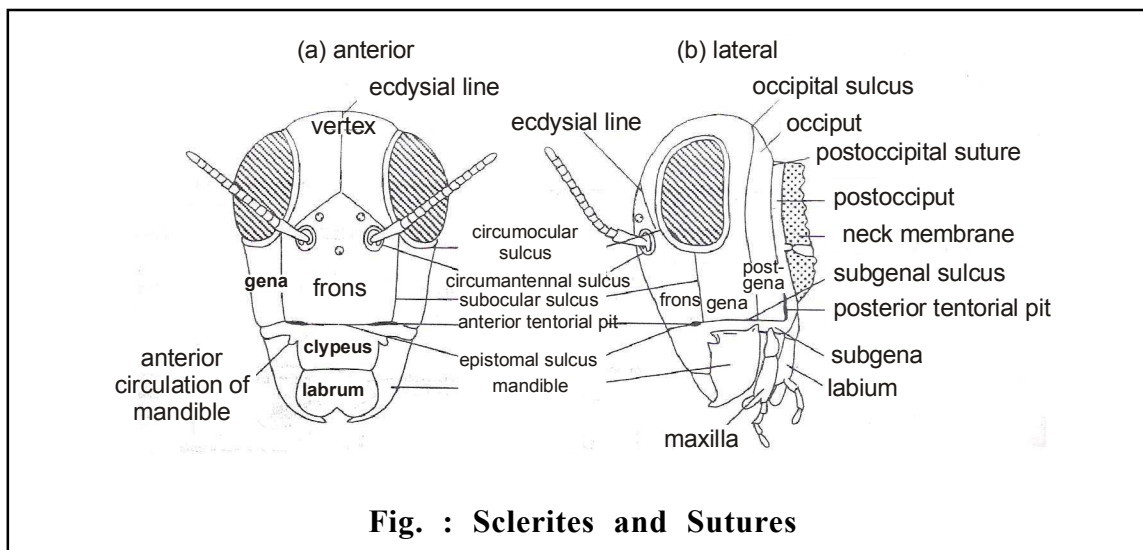
**The Epicranium :** The epicranial suture separates epicranium from the frons. It represents the entire upper region or top of the head. It extends from anterior frontal to the posterior occipital suture. Epicranium is divided into two lateral plates known as parietals which bear antennae, lateral ocelli and compound eyes. The undivided part is known as vertex. It forms top of the head.

**The Occiput :** It is U shaped. It represents the area from the occipital to the post occipital sutures.

**The Post occiput :** The occipital foramen is encircled from the dorsal and lateral regions by a narrow sclerite called the post occiput. It lies between the occiput and the neck. The post occiput is separated from the occiput by post occipital suture. The antero lateral inner margin of the post occiput produces small process called as occipital condyles. Each condyle articulates with the anterior lateral cervical sclerite.

**The Genae and subgenal areas :** The genae represents the lateral areas of the head. The genea extend from the compound eyes to the mandibular trochantin on both sides. Posterior to the occipital suture each lateral gena is commonly called as post gena. The subgenal areas above and below the mandibles are called as pleurostoma and hypostoma respectively.

**The Occular sclerites :** They form cuticular ring around each compound eyes. The antennal sclerites form an annulus at the base of each antennae. The mandibular trochantin occurs between the mandibular base and the pleurostoma.



### Sutures

The head capsule of the mature insect is differentiated into several regions by the sutures. The sutures are secondarily developed fine grooves

The common sutures of the insect head are

- Epicarnial suture
- Epistomal suture
- Post occipital suture
- Ocular sutures
- Antennal sutures
- Clypeo - labral suture
- Occipital suture
- Subgenal sutures
- Frontogenal or subocular suture

**Epicarnial suture** : It is inverted 'Y' shaped suture. The stem is known as coronal and lateral arms are known as frontal sutures. It is absent in apterygotes. The area delimited by the two arms is called the frons and dorsal region bisected by the coronal suture is called as the vertex.

**Clypeo - labral suture** : It represents the lower margin of the clypeus.

**Epistomal suture** : This is also called as clypeo frontal suture. It occurs between clypeus and frons. It connects subgenal suture across the front of cranium just beneath the frontal suture.

**Occipital suture** : It is horseshoe or U shaped suture. It separates the genal area from the post genal area of the lateral region of the head. It also differentiates



the vertex from the occiput in the posterior region of the head. The dorsal region between the occipital and post occipital suture is called occiput.

**Post occipital suture** : It is present posterior to occipital suture and it surrounds the posterior opening of the head capsule, the foremen magnum. It is only suture having the metameric significance. The plate posterior to the post occipital suture which surrounds the major part of the foremen magnum is called post occiput.

**Subgenal sutures** : These are present on either side of the cranium, immediately above the bases of the mandibles and maxillae. The region above each subgenal suture and anterior to the occipital suture is called gena. The region posterior to occipital suture and adjacent to gena is called the post gena.

**Ocular sutures** : These form the annular grooves around the compound eyes.

**Frontogenal or subocular suture** : It develops on the lateral region of the head. It starts from the junction of the clypeo frontal and the subgenal sutures. It terminates close to the lower margin of the each compound eyes.

**Antennal sutures** : The marginal depressed ring around the antennal sockets are known as antennal sutures.

## 2.4 HEAD AND HEAD APPENDAGES

### Head

Insect head is a hard and highly sclerotized compact capsule. It bears externally a set of sensory and gnathal appendages. The sense organs include, a pair of antennae, a pair of compound eyes, and two or three ocelli. The gnathal appendages comprise of a pair of mandibles, a pair of maxillae and a labium.

### Head Appendages

The head or gnathal appendages consist of

1. Paired mandibles
2. Paired maxillae
3. Labium
4. Hypo pharynx

1. **The mandibles** : These are strongly chitinized structures and are commonly known as jaws. In pterygotes and Lepismatidae the mandibles are dicondylic. In Apterygote, the mandibles are monocondyle. The mandibles carry out function of biting and chewing the food material in Orthopteran insects. They are adapted into stylet like piercing organs in fluid sucking insects.
2. **The maxillae** : These are also known as second pair of jaws of insects. Each maxillae is composed of cardo, stipes and palpifer. The palpifer forms the maxillary palp which is antennae like in shape. Maxilla is distally composed of two lobes, namely outer lobe galea and inner lobe lacinia. The maxillae are functionally a

pair of sensory jaws where lacinia helps mandibles in holding the food as well as assisting in mastication.

3. **Labium** : It is formed from the fusion of paired second maxillae. It is also known as lower lip of the insects. The labium is composed of the distal prementum and the proximal post mentum. The prementum and post mentum are separated by labial suture. The post mentum is subdivided into a proximal segment, the submentum and the distal one the mentum. The prementum bears a pair of lateral 3 segmented labial palpi and distally 4 lobes, two inner lobes called glossae, located between two outer lobes called paraglossae. In some insects the lobe of the both pairs fuse together and form a single structure, the lingua. The labial palpi are attached to the lateral sclerites on the prelabium, the palpigers. The prementum closed the preoral cavity from behind and the palpi are mainly sensory in function.
4. **Hypo pharynx** : It is a fleshy tongue, arising from the floor of mouth or preoral cavity and is usually attached to inner wall of labium. The salivary glands open through it.

## 2.5 TYPES OF MOUTH PARTS AND ANTENNAE

### ■ Antennae

Insect antennae has three basic parts namely, the basal scape, pedicel and long flagellum at the distal end. The scape articulates in an antennal socket. The movement of the antennae is facilitated by the muscles inserted on the base of the scape. The pedicel in most of the insects contains special sensory organ called the Johnston's organs.

#### Modification of antennae

| S.No. | Type of antennae             | Description                                                                                        | Example                      |
|-------|------------------------------|----------------------------------------------------------------------------------------------------|------------------------------|
| 1     | Arsitate<br>(with a bristle) | The flagellum bears a heavy bristle known as arista                                                | House flies                  |
| 2     | Capitate<br>(Knobbed)        | The terminal segment suddenly enlarge to form a large knob or cap                                  | Nitidulid beetles            |
| 3     | Clavate<br>(Clubbed)         | The segments increase in thickness gradually and the last segment finally ending into a round cone | Butterflies                  |
| 4     | Filiform<br>(Thread like)    | Uniform sized segments and cylindrical in shape                                                    | Grasshoppers, ground beetles |

|    |                             |                                                                                                                            |                                   |
|----|-----------------------------|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| 5  | Geniculate<br>(Elbowed)     | First segment long, second segment short and flagellum made of small segments which are bent on the scape like a bent knee | Chalcid flies                     |
| 6  | Lamellate<br>(Leaf like)    | The terminal segment enlarge to rounded or oval plate like lobe                                                            | Scarabaeid beetles                |
| 7  | Moniliform<br>(Bead like)   | All segments are uniform thickness and spherical in shape                                                                  | Isoptera                          |
| 8  | Pectinate<br>(Comb like)    | Segments are long, slender and bear lateral process                                                                        | Silk moth                         |
| 9  | Plumose                     | With inter segmental hair circlets                                                                                         | Male mosquitoes                   |
| 10 | Serrate<br>(Saw like)       | Triangular segments, particularly in the distal half of the antennae                                                       | Buprestid beetles                 |
| 11 | Setaceous<br>(Bristle like) | The size of each segment becomes smaller and tapering at the end                                                           | Odonata, cockroaches, leafhoppers |
| 12 | Stylate<br>(with a style)   | The last segment is modified into a long bristle known as style                                                            | Horse flies, robber fly           |
| 13 | Whorled                     | Usually setaceous, filiform or moniliform type with one or more whorls of hairs around each segment                        | Male mealy bug of mango           |

### ➤ Modifications of insect mouthparts

The various types of modification of insect mouth parts are

1. Chewing
2. Piercing and sucking
3. Chewing and lapping
4. Rasping and sucking
5. Siphoning
6. Sponging

#### 1. Chewing

This type of mouthparts are regarded to be primitive and are found in Apterygota, Paleoptera, Dictyoptera, Orthoptera, Coleoptera and other insects which feed on solid food material. The mandibles are hard, chitinous, toothed structures, fitted to work transversely and used for cutting, tearing and mastication of food. The maxillae

are provided with powerful lacinia and galea, which help in cutting and grinding.

## **2. Piercing and sucking**

In plant feeders like cicadas and aphids, the piercing-sucking needle is formed from 4 stylets fitted closely together. The outer stylets are derived from mandibles, and inner stylets are derived from maxillae. The maxillae are double grooved on inner side and when held together, from two channels one is for the passage of saliva into the plant to facilitate food flow and digestion and other is for the uptake of plant juices. The labium forms the protective sheath for the stylets.

In blood feeding insects like mosquitoes, an elongate labium forms a protective sheath for 6 stylets formed by two mandibles, two maxillae, one each hypo pharynx and labrum epipharynx which forms a food channel. The back of the food channel is closed by the hypopharynx with its salivary duct. This duct carries saliva with enzymes and anticoagulants that reduce blood clotting in the host. The maxillary and mandibular stylets work together as needle to penetrate the host skin. By the sucking action of the pharynx blood is sucked into the tube and this passes through the epipharyngeal groove into the buccal cavity

## **3. Chewing and lapping**

These type of mouthparts are found in honey bees. The labrum and the mandibles are of the chewing type, but the maxillae and the labium are united and elongated to form the lapping tongue, that can be protracted and retracted to reach by which they collect nectar from flowers. Food channel is formed by galeae, glossa and labial palps. The mandibles are used for carrying things and for moulding the wax into cells. Mandibles are not involved in the feeding process.

## **4. Rasping and sucking**

The rasping and sucking type of mouthparts are intermediate in structure between the piercing-sucking and chewing- lapping types, and are found in thrips. They are asymmetrical due to the absence of right mandible. With these mouthparts the insects lacerate the plant epidermis and suck the sap as it exudes. The mouth parts consist of single elongated slender mandibular stylet, two piercing maxillary (laciniae) stylets and a short median lobular hypophayrnx. In this type, the mouth parts move in and out through an opening in the apex of the cone shaped head. They do not form food channel and do not enter the wound deeply.

## **5. Siphoning**

This type of mouthparts is found in adult Lepidoptera. The labrum is reduced, maxillary palpi are rudimentary, mandibles are absent and the labium may be large, heavy or scaly. The galeae of these maxilla form the major part of the mouthparts.

They are very much elongated and join to form a hollow slender tube (proboscis) which is coiled up under the head like a watch-spring. At the time of feeding, it is unwound, elongated and nectar or juice is sucked through it.

## 6. Sponging

This type of mouth parts are found in house fly. The mandibles are absent hence they are incapable of piercing the skin. Maxillae are represented by maxillary palpi. On the lower side of the head there is a fleshy, elbowed proboscis (feeding apparatus) which can be folded and withdrawn. Proboscis is formed from the labrum, hypo pharynx and labium. Its base the rostrum (which is modified clypeus), and the distal haustellum, at the end of which is the sponge-like structure labellum is present which is rich in pseudo tracheal channels. Food canal lies between the labrum and hypo pharynx leading to functional mouth, situated behind the base of labrum.

## 2.6 THORAX

The thorax is a well differentiated middle part of the insect body and it consists of three segments. They are

1. Prothorax                      2. Mesothorax                      3. Metathorax

Winged insects have a pair of wings on the meso and meta thoracic segments and these two segments are collectively known as pterothorax

### Morphology of thorax

The main segmental regions of each thoracic segment are

- a. Dorsal tergum (pl. terga)
- b. Ventral sternum (pl. sterna)
- c. A pair of bilateral pleura (singular pleuron)

The legs articulate with pleura and the wings articulate between the tergum and pleuron.

### a. Tergum

In some insects, the tergum of each thoracic segment is undivided and called as notum. The terga of the thoracic segments from front to backwards are referred to as pronotum, mesonotum and metanotum. The tergum of the prothoracic segment is known as pronotum. The muscles of the first pair of legs are attached to it. The mesonotum and metanotum (pterothorax segments) are divided into three distinct sclerites, the prescutum, the scutum and scutellum. They also contain acrotergite and postnotum which are of inter segmental origin.

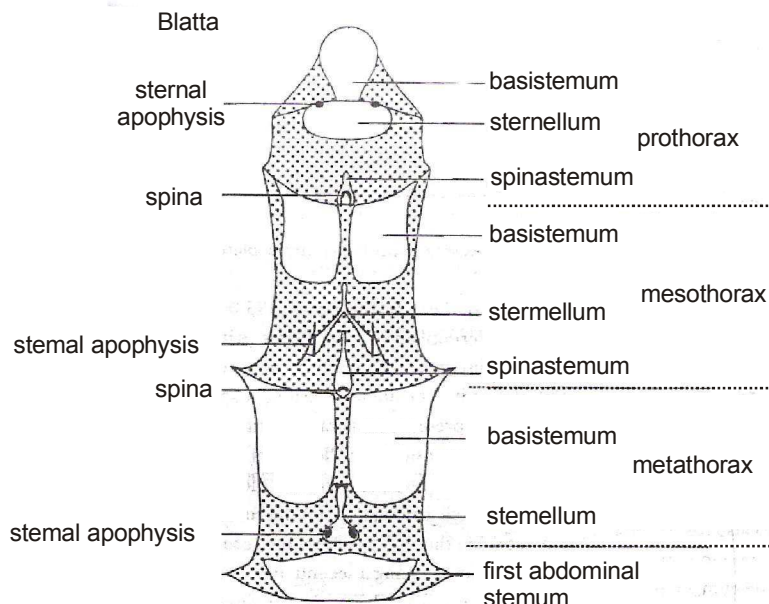


Fig. : Thorax

**b. Sternum**

The sternum of pro, meso and meta thorax consists of eusternum and spinasternum. The eusternum is subdivided into three main regions, the presternum, the basistemum and sternellum. The spinasternum also called as the poststernellum. It produces internally a peg like apodeme, called as spina for the attachment of muscles.

**c. Pleuron**

The basal segment of the primitive leg is fully incorporated into the body to form the pleuron. The pleuron is similar in all the three segments and is called as the propleuron, and the pteropleuron. The pleuron of each side consists of three sclerites, sternopleurite on ventral side and anapleurite and coxopleurite on dorsal side.

The pleuron of the pterothoracic segments is divided into anterior episternum and a posterior epimeron by a pleural suture. The articular membrane between the episternum and the coxa bears a small sclerite called trochantin. The epimeron and episternum are subdivided into smaller sclerites called epipleurites lying at the base of the wing. When these lie anterior to the pleural wing process they are called basal plates and when posterior are termed subalar plates.

The pleura of the meso and metathoracic segments bear a pair of spiracles.

## 2.7 THORACIC APPENDAGES AND THEIR MODIFICATION

### ■ Thoracic appendages

There are 2 types of thoracic appendages

- I. The legs
- II. The wings

#### I. The Legs

The insect leg is composed of six distinct segments (from anterior to distal end) namely, 1. A basal coxa (pl coxae), 2. Small trochanter, 3. Femur, 4. Tibia (pl tibiae), 5. Segmented tarsus (pl tarsi), and 6. Pretarsus.

1. **Coxa** : It is tubular, broad, triangular, oval or spherical in shape. The proximal part is known as subcoxa. The subcoxa is attached to the pleuron by an articular membrane called the coxal corium.
2. **Trochanter** : It is small segment some times divided into two (Odonata). It is freely movable by a hinge joint on the coxa and it firmly fixed with femur.
3. **Femur** : It varies in shape and size in different insects. It is the largest and strongest part of the leg and in the hind leg of Orthoptera it is very much enlarged for leaping.
4. **Tibia** : It is generally slender and long and provided with spines in some insects. It bears a single or many tibial spurs on the distal end.
5. **Tarsus** : The tarsus is usually made up of 2 to 5 segments, the tarsomeres but it is unsegmented in primitive insects. On the lower surface of each tarsal segment are small pads, the pulvilli or plantulae.
6. **Pretarsus** : It is terminal part of the leg. It bears a pair of movable lateral claws and between them is median pair called the arolium and a median bristle called the empodium. On the ventral side the pretarsus bears a median plate, the unguitractor for attachment to the flexor muscles of the claws.

### Modifications of the insect leg

| S.No. | Type of leg                                  | Description                                                                                                                                                                                                                                                                               | Example                            |
|-------|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| 1     | Ambulatorial (Walking legs)                  | Coxa is small, femur is slender and flat and tibia is long. Pretarsus provided with long claws                                                                                                                                                                                            | Dermaptera, ants                   |
| 2     | Climbing or sticking (Adhesive type of legs) | Pretarsus is highly modified and represented by a pair of claws and a pair of pad like structure, pulvilli found at the base of claws. They are densely clothed with numerous hairs which secrete sticky substance                                                                        | House fly                          |
| 3     | Corbiculate (Pollen collecting legs)         | The tibia of hind leg is dilated and covered with long dense hairs forming a pollen basket. The first tarsal segment is flattened & its inner surface is densely clothed with several rows of spines forming a brush. It helps in collecting the pollen adhering to the hairs of its body | Hind legs of worker honey bees     |
| 4     | Cursorial (Walking and running legs)         | Similar to ambulatorial legs. Tarsi are long and touch the ground while running                                                                                                                                                                                                           | Cockroaches, tiger beetles         |
| 5     | Fossorial (Digging legs)                     | Tibia and tarsi are flattened and shaped like shovels for digging the soil                                                                                                                                                                                                                | Forelegs of gryllotalpids          |
| 6     | Natatorial (Swimming legs)                   | Femur, tibia and first four tarsomeres are broad and flat with marginal setae forming oar like structure                                                                                                                                                                                  | Aquatic bugs, beetles              |
| 7     | Raptorial (Prehensile legs)                  | These are adapted for catching and holding the prey in between the greatly enlarged and ventrally grooved femur and blade like curved tibia                                                                                                                                               | Fore legs of mantids, aquatic bugs |
| 8     | Saltatorial (Leaping / jumping legs)         | Femur is enlarged. Tibia is elongated and is spined dorsally, when it strikes the ground surface the insect jumps or leaps                                                                                                                                                                | Grasshoppers, crickets             |



|    |                                             |                                                                                                                                                                            |                               |
|----|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| 9  | Scansorial<br>(Clinging /<br>clasping legs) | Padded projection is present at the distal end of tibia and pretarsus is modified into an enlarged claw shaped structure which fits on the pad                             | Head lice                     |
| 10 | Stridulatorial<br>(Sound producing)         | Femur of hind leg is provided with a pair of pegs on its inner side. These rub against outer surface of each tergum for coastal margin of fore wing there by produce sound | Crickets and male grasshopper |

## 2.8 WING MODIFICATION AND VENATION

### The wings

In insects there is normally two pairs of wings, the fore wings and hind wings except in Diptera there is only one pair, hind wings are reduced to halteres. The wings of adult insects are articulated to the sides of the meso and meta thoracic terga by a complex group of sclerites.

### Wing veins and venation

The support of the wing membrane is provided by cross veins

A vein on a crest is called convex (indicated by +)

A vein on the trough is called concave (indicated by –)

From leading edge of the wing backwards they are

Costa (C)

Subcosta (Sc)

Radius (R)

Radial sector (Rs)

Anterior media (MA)

Posterior media (MP)

Anterior cubitus (CuA)

Posterior cubitus (CuP)

Anal (1A, 2B etc.)

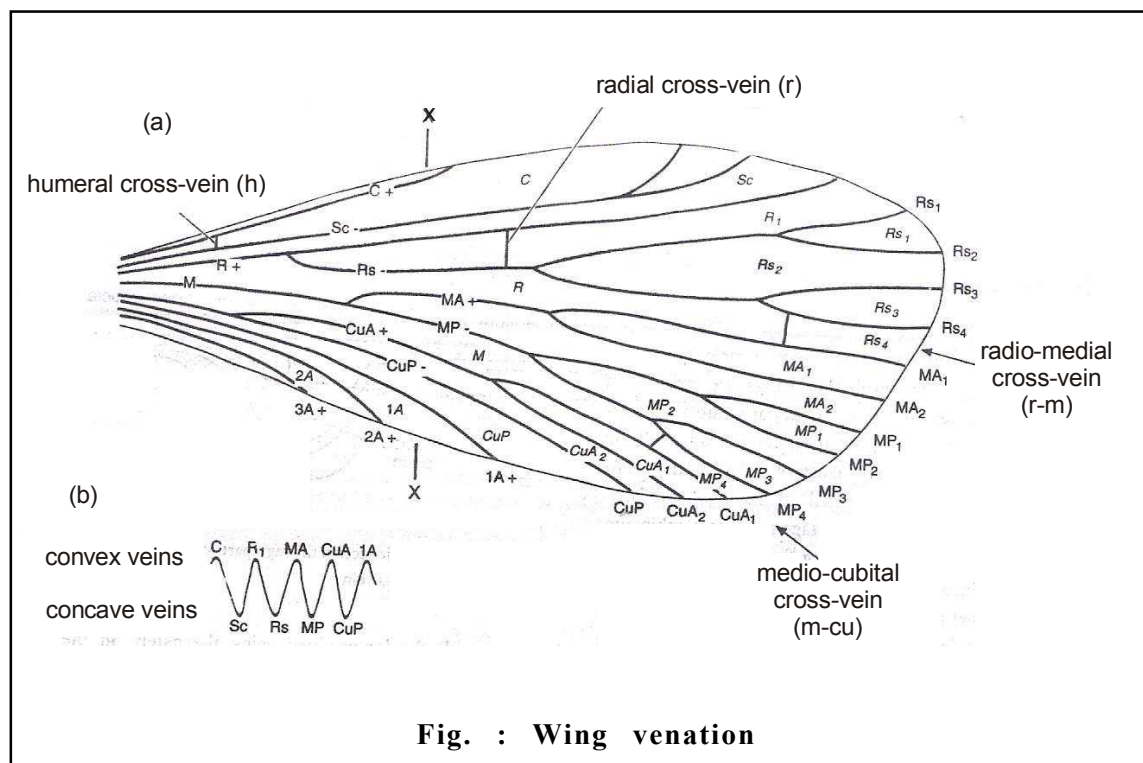


Fig. : Wing venation

### ➤ Areas of the wing

The region containing the bulk of the veins in front of the claval furrow is called the remigium

The area behind the claval furrow is called the clavus and except in hind wings this area is expanded and is known as the vannus

The leading edge of the wing is called the costal margin

The trailing edge is called anal margin

The outer edge is called apical margin

The angle between the costal and apical margin is called apical angle

The angle between the apical and anal margin is called anal angle

The angle at the base of the wing is called the humeral angle

On the anterior margin of the wing in some insects there is a pigmented spot known as Pterostigma

The wing veins of archedietyon plan are listed below:

1. **Precoasta (PC):** This vein is fused with costa in all extant insects, mostly unrecognisable.
2. **Costa (C):** At the leading edge of the wing, strong and marginal, extends to the apex of the wing, it is unbranched.
3. **Subcosta (Sc):** The second longitudinal vein, mainly the subcosta posterior sector (ScP). Sc is reduced or fused with R in most Hemiptera.
4. **Radius (R):** The third vein, usually the **strongest** vein on the wing, with branches usually cover the largest area of wing apex. RP (radius posterior) is often referred to as radial sector (Rs) and the end branches as R1-5.
5. **Media (M):** The fourth longitudinal vein, MA and MP usually with 4 branches each. In some insect groups MA fused with R so only MP on the medial area. In this case the MP1-4 are often referred as M1-4.
6. **Cubitus (Cu):** Fifth longitudinal vein, CuA (Cubitus Anterior) may branch to 4 or fewer veins. CuP (Cubitus Posterior) is unbranched, lies near the claval fold and reach the wing posterior margin.
7. **Anal veins (A):** Veins behind the cubitus, AA (anal anterior) and AP (anal posterior) are usually separated by the anal fold. In Neoptera, AA is always fused with Cu or CuP. In the hind wings of most orthopteroid insects, there is a large anal area where anals branch several times to form a fan-like folded wing.
8. **Jugal (J):** Small veins in the jugal area, found only in Neoptera.

Cross-veins are transverse veins joining longitudinal veins to provide rigidity of the wings. Their names are based on the position relative to longitudinal veins. In Orthoptera and Odonata the cross veins are numerous but in other insects there is a definite number of cross veins, with specific positions and designations.

The main cross veins are:

- (i) **Humeral** cross vein (h)-lies between the costa and the subcosta.
- (ii) **Radial** cross vein (r)-lies between the R1 and first four of Rs.
- (iii) **Sectorial** cross vein (s)-lies between two forks of Rs.
- (iv) **Median** cross vein (m)-lies between the second and third media  $M_2$  and  $M_3$ .
- (v) **Median-cubital** cross vein (m-cu)-runs between the media (M) and cubitus (Cu).
- (vi) **Radial-median** cross vein (r-m)- runs between the radius and media.

The black **pterostigma** is carried near the wing tip, between RA1+2 and RA3+4.

➤ **Wing Coupling mechanisms**

The various types of wing coupling mechanisms observed in insects are

- Primitive type
- Jugate wing coupling
- Frenate wing coupling
- Jugo frenate wing coupling
- Hamuli wing coupling
- Amplexiform wing coupling

**a. Primitive type**

There is jugal lobe at the base of the forewing and a humeral lobe at the base of the costal margin of the hind wing. Both lobes are set with setae known as jugal and frenular bristles respectively. These overlap and both wings move together.

Ex : Family Choristidae of Mecoptera

In some insects only jugum is present it lies on the top of the hind wing.

Ex : Trichoptera

**b. Jugate wing coupling**

Strong jugal lobe lies beneath the costal margin of the hind wing. This is held between the jugum and the rest of the forewing.

Ex : Hepialidae (Lepidoptera)

**c. Frenate wing coupling**

Well developed frenulum which engages with retinaculum on the under side of the forewing.

Ex : Lepidoptera

**d. Jugo frenate wing coupling**

The jugum is folded under the forewings and holds the frenular bristles.

Ex : Micropterigidae

**e. Hamuli wing coupling**

They have row of hooks, the hamuli, along the costal margin of the hindwing which catch into a fold of the forewing

Ex : Hymenoptera

**f. Amplexiform wing coupling**

The wings are coupled by the virtue of an extensive area of over lap between the two wings.

Ex : Papilionoidea and Bombycoidea

**➤ Wing modifications**

There are 5 types of wing modifications usually observed in insects

- |             |                   |              |
|-------------|-------------------|--------------|
| 1. Tegmina  | 2. Elytra         | 3. Hemelytra |
| 4. Halteres | 5. Pseudohalteres | 6. Fissured  |
| 7. Fringed  | 8. Membranous     | 9. Scaly     |

- 1. Tegmina :** These are the forewings of Orthoptera, Dictyoptera and Phasmida, which are tough and leathery.
- 2. Elytra :** The forewings of Coleoptera and Dermaptera are much hardened to form a horny sheath, which protect the membranous hind wings.
- 3. Hemelytra :** This type of wing is found in Heteroptera (Hemiptera), where the forewings are hardened apically but is membranous distally and is called hemelytra or half-elytra. It is divided into two parts. Clavus, a basal narrow area near scutellum and corium or terminal broad area. Corium is again divided into a dorsal coastal narrow strip called embolium and a triangular apical region called cuneus.
- 4. Halteres :** The hind wings of Diptera are modified into clubbed shaped halteres. These are extremely small and are very slender proximally but knobbed distally. These help to maintain stability or balance during flight.
- 5. Pseudohalteres :** The forewings of Strepsiptera. These are very small and club shaped and help in balancing the body during flight.
- 6. Fissured or clofted :** Both wings of plume moth. The front wing is longitudinally divided forming a fork like structure where as hind wing is divided twice resulting into two forks with three arms. All the forks have small marginal hairs.
- 7. Fringed :** Both wings of thrips. The wings are highly reduced, narrow and membranous with highly reduced wing venation. The wings are fringed with long marginal hairs giving a feather like appearance.
- 8. Membranous :** Both wings of dragon flies, wasps, bees and forewings of flies. Hind wings of grasshoppers, beetles and bugs. The wings are always thin, membranous with highly developed venation. These are useful for flight.
- 9. Scaly :** Both wings of butterflies and moths. The wings are thin, membranous but covered with over lapping scales all over the surface hence the name scaly wings. These wings are useful for flight.

## 2.9 ABDOMEN

### ■ Abdomen

It is the third or hind part of insect body. In most of the insects the primitive number of abdominal segments are 11 and a small terminal telson, except in Collembolans which possess 6 segmented abdomen. The terminal segment bears a pair of appendages, the cerci. The 11<sup>th</sup> segment has three plates, namely an epiproct dorsal to anus and two paraprocts, one on either side of the anus. The first abdominal segment bears spiracles on either side. In Protura there is tendency of addition of segments during development called as Anamorphosis and they retain distinct telson.

#### Abdominal appendages

There are three types of abdominal appendages present in insects. They are

- I. Pregenital appendages
- II. Genital appendages
- III. Post genital appendages

- I. Pregenital appendages :** The segments prior to 8<sup>th</sup> abdominal segment are called pregenital segments and the segmental appendages present on these segments are called as pregenital appendages.

The ventral tube of the adult Collembola is formed by fusion of a paired appendages of 1<sup>st</sup> abdominal segment. Adult Protura and Diplura also bear a pair of appendages on the first abdominal segment known as pleuropodia.

- a. Styli form appendages :** These are common in Apterygota insects. Thysanura have styli on 2<sup>nd</sup> to 9<sup>th</sup> abdominal segments. These styli are absent on 1<sup>st</sup> and 10<sup>th</sup> abdominal segment. Protura bear paired appendages on the first three abdominal segments with a protusible sac. Diplura bear pregenital appendages on 1<sup>st</sup> to 7<sup>th</sup> abdominal segments.
- b. Collembolan appendages :** Collembolans possess three pregenital appendages called the collophore, tenaculum and furcula on 1<sup>st</sup>, 3<sup>rd</sup> and 4<sup>th</sup> abdominal segments respectively. The first abdominal segment bears ventrally the median tube called collophore. It functions as adhesive organ. The third abdominal segment bears a minute median organ on the ventral side called as tenaculum. It is also called retinaculum or hamula. It helps in springing process by holding the flexed furcula. The 4<sup>th</sup> abdominal segment bears a springing or leaping organ on the ventral side called as furcula.

- c. **Gill like appendages** : The larvae of *Sialis* (Neuroptera) bear paired lateral long appendages on 1<sup>st</sup> to 7<sup>th</sup> abdominal segments. Similar type of abdomen appendages are also found in aquatic Dytiscidae and Gyrinidae of Coleoptera.
- d. **Prolegs of caterpillars** : Lepidopteran caterpillar possesses 5 pairs of prolegs. Four pairs on the 3<sup>rd</sup> to 6<sup>th</sup> abdominal segments and 5<sup>th</sup> pair on the 10<sup>th</sup> abdominal segment. These help in locomotion. The end of the prolegs bear curved claw or crochets and an adhesive planta.

**II. Genital appendages:** In pterygotes, functional genitalia are present on 8 and 9 abdominal segment in females and 9<sup>th</sup> abdominal segment in males. These segments are therefore called as genital segments and the appendages present on these abdominal segments are called as genital appendages. The genital segments bear appendages called genital organs and these constitute external genitalia. They help in copulation and sperm transfer in males and oviposition in females.

**a) The male genitalia**

The male genital opening is on the posterior side of the 9<sup>th</sup> abdominal sternum. It exhibits wide variation in different insects and is of taxonomic importance. In Collembola the opening is present on 5<sup>th</sup> abdominal segment. At the male genital opening an organ called penis or phallus is present which is used for the transfer of sperms. The penis is bi-lobed in some Epimeroptera and earwigs. A pair of forceps like structures is present on either side of phallus called parameres and these are used as clasping organs. The inner wall of the phallus is membranous and is called as endophallus.

The genital structures arise from a pair of small ectodermal outgrowths behind 9<sup>th</sup> sternum called phallic lobes. Each primary phallic lobe is divided into secondary lobes or phallomeres, the median pair is termed as mesomere and the lateral ones are called as parameres. The mesomeres on both sides unite to form a tubular median aedeagus. The opening at the distal end of the aedeagus is known as phallotreme.

**b) Female genitalia**

**Ovipositor** : The female genitalia mainly consists of simple egg laying tube known as ovipositor. It is communicated with the basal gonopore which is located on either 8<sup>th</sup> or 9<sup>th</sup> abdominal segments. In tubuleferous Thysanoptera substitutional ovipositor represents simply a telescopic tube which is formed due to modification of the posterior abdominal segments into a tubular extension which acts as egg laying tube. In fruit flies the last abdominal segments (7 to 11) modify into a tapering tubular structure which is pointed at the end for piercing the skin of fruits for ovipositing the eggs.

The ovipositor is composed of a shaft and a basal apparatus. The shaft is made up of the first and second pairs of closely appressed elongated processes, the valvulae. The basal apparatus consists of two pairs of lobes or plates, the first and second valifers which provide support to the shaft by the bases of the valvulae.

In Hymenopterans like bees and wasps the ovipositor loses its egg laying capacity and is converted into poison injecting organ known as sting.

**III. Post genital appendages :** The 11<sup>th</sup> abdominal segments of some insects bears a pair of appendages called the cerci which are considered as post genital appendages.

- a) **Cerci :** These appendages are present on 11<sup>th</sup> abdominal segment. They develop in between the epiproct and paraprocts. In some insects they represent sexual dimorphism. In *Calliptamus* (Orthoptera), females have simple conical cerci, while males bear long, flattened lobulated structures. Asymmetrical anal cerci are present in male Embioptera. Saw like anal cerci are present in male Dermaptera. They are primarily tactile organs and are provided with the trichoid hairs. They may also function as clasping organ in Embioptera or swimming organs in nymphs of Ephemeroptera or feeding organs in Japygidae.
- b) **Secondary copulatory apparatus in Odonata :** In male dragonflies, the primary external genitalia is almost rudimentary. The functional genitalia is the secondary copulatory apparatus, is developed on the ventral surface of the second and third abdominal segments. It consists of anterior and posterior lamina, genital lobe, genital fossa, supporting frame work, hamules, ligula and penis. The structural variations of the secondary copulatory apparatus are species specific and are of great taxonomical significance.







# Embryology, Internal Anatomy and Physiology

## 3.1 EMBRYONIC DEVELOPMENT

### ■ Embryonic development

Development of an insect, means from egg to adult is called embryonic development  
It can be divided into 2 parts

- I. Pre embryonic : Development takes place inside the egg
- II. Post embryonic : Development takes place outside the egg

#### I. Pre embryonic development

**The sequences of steps that are involved in early embryonic development are**

- 1. Cleavage
- 2. Blastoderm formation
- 3. Vitellophages
- 4. Germ band formation
- 5. Germinal layer formation
- 6. Formation of amniotic cavity and extra embryonic membranes
- 7. Blastokinesis
- 8. Segmentation and appendages
- 9. Organogenesis
- 10. Eclosion

The early embryonic development of insects starts with cleavage

- 1. **Cleavage** : The ova of most of the insects is centro lecithal and meroblastic. Cleavage is superficial. Except in Collembola where the eggs are isolecithal and holoblastic.

**Energid** : After fusion of egg and sperm the diploid nucleus divide and produce

a number of daughter nuclei. Each daughter nuclei surrounded by halo mass of cytoplasm forming independent cell called as energid or cleavage cell.

2. **Blastoderm formation** : The energids migrates towards the periphery of the egg and arrange in a layer of circle with in the yolk. The energids undergo repeated mitotic divisions and forms a continuous layer of cells. This is called blastoderm. It lies just beneath the vitelline membrane.
3. **Vitellophages** : In some insects all energids do not migrate to periphery to form blastoderm but some of them lie behind with in the yolk and are called yolk cells or vitellophages. Initially these multiply mitotically after 6 or 7 divisions they increase in size through endo mitosis. Ex: Diptera. In some insects some cells migrate back from the blastoderm to form vitellophages. These are called secondary vitellophages.
4. **Germ band formation** : With the formation of blastoderm the egg attains blastula stage of development. The blastoderm initially appears as uniform thin layer covering the yolk. After some time in the ventral region of the egg the cells undergo cell divisions repeatedly to form germ band. This later develops into embryo. The dorsal thin part of blastoderm remains as extra embryonic membrane which is termed as serosa. The germ band membrane is also know as germinal disc or primitive band.
5. **Germinal layer formation** : The embryonic stage which involves the formation of germinal layers (endo, meso and ectoderm) is called gastrulation. In insects there is no differentiation between gastrulation and blastulation. Germinal layers develops from inner layer of cells lying immediately beneath the germ band. The germ band differentiates into middle and two lateral plates, as the middle part of it sinks inward into a deep groove and retains a form of primitive streak. It is a double layer flattened tube.  
  
The lateral plates fuse with each other in the middle over middle plate and form ectoderm. Middle plate modified into middle and two lateral strands. The middle strand develops into endoderm and the two lateral strands develop into mesoderm.
6. **Formation of amniotic cavity and extra embryonic membranes** : Soon after the formation of germ band the serosa along with the yolk from either side extends laterally until both extensions meet and fuse in the ventral mid line as result, formation of small cavity on ventral surface of germ band takes place called the amnion. The amnion and serosa may be connected or separated mid ventrally.
7. **Blastokinesis** : The embryo begins to move with in the yolk, undergoing rotations, revolutions and marked displacements, the phenomenon is called the blastokinesis.

It is of 2 types

- i) **Anatrepsis** : The movements taking place from the posterior to anterior pole of egg are termed as anatrepsis.
- ii) **Katatrepsis** : The movements taking place from ventral to dorsal surface of the egg are called katatrepsis.

- 8. Segmentation and appendages** : With the differentiation of germinal layers, the germ band begins the process of metamerism. The first division appears between the future labium and thoracic segments dividing the embryo into broad head region, procephalon and long narrow posterior trunk protocorm.

The unsegmented anterior part of procephalon is called acron which bears unsegmented antennal lobes. The unsegmented protocorm represents abdomen. This stage of development is called protopod phase. This advances into polypod phase with complete segmentation of abdomen and budding of abdominal appendage rudiments. Polypod advances into oligopod phase in which abdominal appendages disappear except first pair called the pleuropodia. Terminal appendages develop into genital organs.

**9. Organogenesis :**

**Ectoderm** : It produces, integument, tracheal system, nervous system, sense organs, antennae, mandibles, maxillae, labium and fore and hind gut and other appendages.

**Mesoderm** : It give rises to coelomic sacs, muscles, circulatory system, haemocytes, pericardial cells, fat body, gonads, blood and heart.

**Endoderm** : It give rises to midgut.

- 10. Eclosion** : Extra embryonic membranes, serosa and amnion both rupture and disappear with the progress of organogenesis. At the time of eclosion the egg shell ruptures by intrinsic mechanism *i. e.* internal muscle contraction (Ex: *Gryllus*) or by ptilinial mechanism (Ex: *Cyclorrhapa*) or by extrinsic mechanism as seen in *Lepidoptera*.

## 3.2 TYPES OF METAMORPHOSIS

### ■ Metamorphosis

The process of development of an embryo into adults through a series of successive transitional, morphologically alike or variable forms is known as metamorphosis.

➤ **Types of metamorphosis**

1. **Ametabola** : There is no metamorphosis and immature stages appear very similar to the adults, except that they lack genitalia.

Ex : Collembola, Protura and Diplura

2. **Holometabola** : This is complete metamorphism. There are four distinct stages of development, viz. egg, larva, pupa and adult.

Ex : Lepidoptera, Coleoptera, Hymenoptera, Diptera, etc.

3. **Hemimetabola** : This is incomplete metamorphism. The immature instars are usually similar to the adults in lacking wings and well developed reproductive organs. No pupal stage and immature stages are called nymphs.

Ex : Orthoptera, Hemiptera, Isoptera, Dermaptera, etc.

4. **Hypermetabola** : They have more than four stages in their life cycle. Ex: Blister beetle. The pupa develops into subimago stage prior to the imago stage. Ex: Bombyliidae

➤ **Differences between holometabola and hemimetabola**

| <b>Holometabola</b>                                                                           | <b>Hemimetabola</b>                                                                                                                 |
|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| It is a characteristic of endopterygote insect orders                                         | It is characteristic of the exopterygote insect orders                                                                              |
| This is complete metamorphism                                                                 | This is incomplete metamorphism                                                                                                     |
| Insects undergo through distinctive larval, pupal, and adult stages                           | The immature stages are called nymphs                                                                                               |
| The feeding habit and habitat is different for young stage and adult                          | The place of living is same in young and adult stage                                                                                |
| Wing developemt inside the body. Hence they are not seen outside the body before adult stage  | They develop wings on the outside of their bodies. Wing buds / wing pads visible outisde in the 3 <sup>rd</sup> instar of young one |
| Transformation of the larvae into the adult takes place through a resting stage called a pupa | No pupal stage                                                                                                                      |

|                     |                                                                                                         |                                                                                                                                                               |                                                     |
|---------------------|---------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| <b>Hemimetabola</b> | <b>Paleometabola</b><br>Nymphs and adults can be differentiated by lack of secondary nymphal characters | <b>Epimetabola</b><br>Apterous insects with very little metamorphosis similar to ametabola                                                                    | Ex Protura, Thysanura                               |
|                     |                                                                                                         | <b>Prometabola</b><br>Nymphs are aquatic with abdominal gills. Sub imago stage with wings which develop into mature winged adult                              | Ex : Ephemeroptera                                  |
|                     | <b>Heterometabola</b><br>Earlier instars appear as larvae and later instars as nymphs                   | <b>Archimetabola</b><br>Nymphs are aquatic with tracheal gills                                                                                                | Ex: Plecoptera and Odonata                          |
|                     |                                                                                                         | <b>Paurometabola</b><br>Nymphs are terrestrial with wing pads, adult characters appear only in last moult                                                     | Ex : Orthoptera, Dictyoptera                        |
|                     | <b>Neometabola</b><br>Degeneration of parts and no considerable metamorphosis                           | <b>Homometabola</b><br>Wing rudiments appear only in last nymph                                                                                               | Ex : winged female of Chermisidae and Phylloxeridae |
|                     |                                                                                                         | <b>Remetabola</b><br>Wingless nymphal stages followed by pronymph and one or two nymphal stages with wing pads                                                | Ex: Thysanoptera                                    |
|                     |                                                                                                         | <b>Parametabola</b><br>Males do not feed. Larval stages are capable of feeding with out wing rudiments. Development is followed by pronymph and nymphal stage | Ex : Male coccidae                                  |
|                     |                                                                                                         | <b>Allometabola</b><br>There are four apterous depressed larval stages of which first alone is free larva                                                     | Ex : Aleyrodoidea                                   |

### 3.3 PHYSIOLOGY OF ECDYSIS

Insect growth is limited by the cuticle which normally undergoes only a limited amount of stretching, so that for any marked increase in size to occur the cuticle must be shed and replaced.

Casting the cuticle is commonly known as moulting but it involves a sequence of events beginning with the separation of the old cuticle from the underlying epidermal cells. This is called apolysis. Moulting ends with the shedding of the remnants of the old cuticle, and this process is known as ecdysis.

After ecdysis the cuticle is expanded and chemically modified and in most insects extensive deposition of new cuticle continues in the inter moult period.

**The various steps involved in the cuticle production are**

1. Changes in the epidermis
2. Separation of the cuticle from the epidermis (apolysis)
3. Digestion of the old endocuticle
4. Ecdysis
5. Formation of epicuticle
6. Production of procuticle
7. Hardening of the cuticle

**1. Changes in the epidermis :** The onset of moulting is usually first indicated by the changes in the epidermal cells which divide and so become close packed and columnar in form. There is net increase in the number of cells per unit area, so that when these are flattened the overall area of the epidermis and cuticle which they subsequently produce is increased. In some insects there is an increase in size of the epidermal cells.

**2. Separation of the cuticle from the epidermis :** As a result of the changes in shape, a tension is generated at the surface of the epidermal cells which result in their separating from the cuticle.

**3. Digestion of the old endocuticle :** The moulting enzymes are secreted into the space known as the exuvial space between the epidermis and the cuticle after apolysis. Initially the enzymes are inactive and they remain in this state until the outer epicuticle of the new cuticle is formed. This is of great importance since otherwise the moulting enzyme would digest the newly formed procuticle as well as the old cuticle.

Activation of the moulting enzymes is probably associated with the active transport

of potassium into the exuvial space accompanied by a bulk flow of water which occurs when the outer epicuticle is complete.

The moulting fluid contains a chitinase and at least one proteinase. These enzymes digest all the unsclerotized cuticle except for the ecdysial membrane but they have no effect on the exocuticle or on the muscle and nerve connections to the old cuticle.

The products of digestion of the cuticle are absorbed and up to 90% of the material present in the cuticle may be conserved in this way. As a result of the activity of the moulting fluid, the cuticle becomes very thin and weak along the ecdysial lines.

4. **Ecdysis** : When the moulting fluid and the products of digestion of the moulting fluid are reabsorbed, the old cuticle consists of little more than epicuticle and exocuticle and it is quite separate from the new cuticle. Usually ecdysis follows as soon as digestion is complete, but some times the old cuticle may be retained for some time and the insect is enclosed is referred to as pharate.

The insect swallows air or water which swells the gut so that hemolymph pressure is increased. This exerts pressure on the old cuticle causing it to split along its lines of weakness. All the cuticular parts are shed, including the intima of fore and hindgut the endo pharangular skeleton and the linings of the trachea except for some delicate parts which may break off. The old cuticle is referred to as exuviae.

Some parts of the skeleton may be hard before ecdysis usually this pre ecdysial hardening is restricted to small parts of the cuticle such as claws, which are essential for the insect to hold.

### ***Cuticle formation***

#### **5. Formation of the epicuticle**

**Outer epicuticle formation:** The first step in the production of the new cuticle is the secretion of the outer epicuticle as patches at the tips of microvilli of the epidermal cells. The patches grow at their margins and coalesce to form a continuous layer over the whole of the epidermis. Lipids proteins, polyphenols and phenol oxidases are produced at the same time.

The surface pattern of the cuticle is produced as the outer epicuticle is formed being moulded by the underlying epidermal cells which develop temporary vacuoles distally. The vacuoles and intercellular spaces disappear as the inner epicuticle is laid down.

**Inner epicuticle formation:** This is secreted when outer epicuticle is complete

and the apical surfaces of the epidermal cells with drawn slightly. It is discharged in vesicles, which coalesce to form a discrete layer, polyphenols are not present until about the time of ecdysis and so tanning of this layer does not take place until some time after its production.

Shortly before ecdysis wax is secreted as to the surface of new cuticle and the layer adjacent to the cuticulin forms the orientation monolayer. The cuticulin adsorbs the hydrophilic polar groups so that the hydrofuge aliphatic groups are towards the outside. The wax is transported to the surface in the epicuticular filaments. Soon after the ecdysis a layer of cement produced by the dermal gland is formed over the surface of the wax.

6. **Production of procuticle:** Production of procuticle begins after the inner epicuticle is laid down. The chitin microfibrils are produced at plaques as the surface membrane of the epidermal cells. The zone of deposition of new cuticle is distinct and is some times called Schmidts's layer.
7. **Hardening of cuticle:** Some hardening takes place before ecdysis, but the bulk occurs soon afterwards when expansion of the new cuticle is completed. The process of hardening involves the development of cross links between proteins chains and is known as tanning or sclerotization. This commonly involves N - acetyl dopamine which is derived from tyrosine. The concentration of this amino acid in the hemolymph increases just before ecdysis and it is taken up by the haemocytes. Dopamine is acetylated to N - acetyl dopamine which is transported into the cuticle. N-acetyl dopamine is then converted into N- acetyl dopamine quinine. As the cuticle hardens it usually also darkens.

**Tyrosine → Dopa dihydroxy phenylalamine → Dopamine → N - acetyl dopamine → N - acetyl dopamine quinine → Tanning**

Procuticle which is produced subsequently remain undifferentiated, so that the insect to have distinct exo and endo cuticle.

**Expansion of the new cuticle :** The insect expands the new cuticle before it hardens. This often involves swallowing air or water. As the procuticle expands it also becomes thinner, partly due to stretching and partly due to dehydration.

**Control of moulting and cuticle production :** Ecdysone is the major hormone concerned with moulting. It initiates apolysis and cuticle production, exerting its effects by inducing specific enzyme activities.

Eclosion hormone – For breaking up the pupae

Bursicone – For tanning



### 3.4 TYPES OF LARVAE AND PUPAE

Insect larvae are of 3 types

1. Oligopod larvae      2. Polypod larvae      3. Apodous larvae

#### 1. Oligopod larvae

Oligopod larvae are hexapodous with well developed head capsule. Mouthparts similar to the adult with no compound eyes.

Oligopod larvae are of 2 types

- a. Campodeiform larva      b. Scarabaeiform larva

**a). Campodeiform larva :** It is well sclerotized. Dorso-ventrally flattened and a long legged predator with prognathous head.

Ex: Neuroptera, Trichoptera, Strepsiptera

**b). Scarabaeiform larva :** It is fat with poorly sclerotized thorax and abdomen. Short legged and inactive forms found in burrowing wood or soil.

Ex: Scarabaeoidea and some Coleoptera

#### 2. Polypod larvae

A polypod larva has abdominal prolegs in addition to thoracic legs. It is poorly sclerotized. These are inactive forms living in close contact with its food.

Ex : Larvae of Lepidoptera, Mecoptera and Tenthredinidae

#### 3. Apodous larvae

It has no legs and poorly sclerotized. Based on the sclerotization of the head capsule, these are of 3 types

**a). Eucephalous :** Well sclerotized head capsule.

Ex : Nematocera, Buprestidae, Cerambycidae

**b). Hemicephalous :** Reduced head capsule which can be retracted within the thorax.

Ex : Tipulidae, Orthorrhaphous, Brachycera

**c). Acephalous :** Without head capsule.

Ex : Cyclorrhapha



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- **Types of pupae**

Based on the presence or absence of articulated mandibles, insect pupae are classified into two forms

1. **Decticous** : Presence of articulated mandibles

Ex : Neuroptera, Mecoptera, Trichoptera and some Lepidoptera

2. **Adecticous** : Absence of articulated mandibles

Ex : Strepsiptera, Coleoptera, Hymenoptera, Diptera and Siphonaptera

Based on the whether the appendages are free or adherent to the body, pupae are classified into 3 types

- a). **Exarate** : The appendages are free and not encapsulated within a cocoon. Decticous pupae are always exarate.

Ex: Megaloptera, Neuroptera, Trichoptera and some Lepidoptera

- b). **Obtect** : The appendages are close to the body and are commonly encapsulated with in a cocoon.

Ex: Lepidoptera, Chalcidoidea, Staphylinidae, Nematocera, Brachycera

- c). **Coarctate** : The pupa is encased in the hardened cuticle of the penultimate larval instar called puparium.

Ex: Cyclorrhapha

- **Other types of pupae**

- a). **Prepupa** : The last larval stage is often quiescent for two or three days before the ecdysis into a pupa. Prepupa is quiescent stage following the last larval stage and it is succeeded by a pupal stage.

Ex : Thysanoptera and male Coccidae

- b). **Chrysalis** : A few insects form unprotected pupae. A chrysalis or nympha is the pupal stage of butterflies. When the caterpillar is fully grown, it makes a button of silk which it uses to fasten its body to a leaf or a twig. Then the caterpillar's skin comes off for the final time. Under this old skin is a hard skin called a chrysalis.

Ex : Nymphalidae and Pieridae

### 3.5 DIGESTIVE SYSTEM

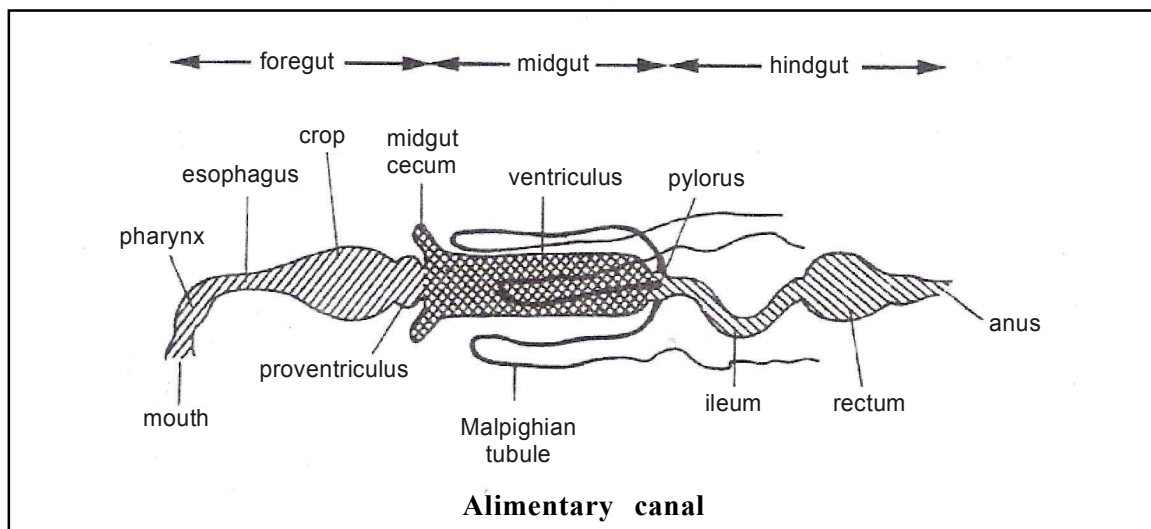
#### ■ Structure of digestive system

##### • Alimentary canal

The alimentary canal of insects is divided into 3 main parts

1. Foregut or stomodeum
2. Midgut or mesentron
3. Hindgut or proctodeum

The foregut and hindgut are ectodermal in origin and have cuticular lining known as intima. The midgut is endodermal in origin and secrete peritrophic membrane.



#### 1. Foregut

- The cells of foregut are usually flattened and undifferentiated since they are not involved in absorption or secretion
- The foregut is differentiated into the pharynx, esophagus, crop and proventriculus
- The pharynx is concerned with the ingestion and passage of food
- The esophagus usually has a simple tubular form serving as a connection between the pharynx and the crop
- The crop is a storage organ which in most insects is an extensible part of the gut immediately following the esophagus

**2. Midgut**

- The cells of midgut are actively involved in enzyme production and secretion as well as absorption of nutrients
- The cells are columnar and have microvilli for increasing the area of absorption
- The cells of the midgut are continuously replaced from regenerative cells at the base of the midgut epithelium these occur in groups known as *nidi*. The tubular part of midgut is known as *ventriculus*

**3. Hindgut**

- The hindgut is usually differentiated into the pylorus, ileum and rectum
- The pylorus forms a valve between the midgut and hindgut
- The Malpighian tubules often arise from it
- The main function of hindgut is to house symbionts and water absorption

**■ Digestion**

The process of digestion include the digestion of

1. Carbohydrates
2. Proteins
3. Lipids

**1. Carbohydrates**

Carbohydrates are generally absorbed as monosaccharides so that before they are absorbed, disaccharides and polysaccharides must be broken down to their component monosaccharides.

Different enzymes involved in this process are  $\alpha$  - 1-4 amylase,  $\alpha$  - 1-6 amylase,  $\alpha$  - glucosidase,  $\beta$  glucosidase, trehalase,  $\alpha$  galactosidase, and  $\beta$  galactosidase.

- **Disaccharides** : The common disaccharides are maltose, trehalose and sucrose. All contain a glucose residue which is linked to a second sugar residue by an  $\alpha$ -linkage. All these are hydrolyzed by  $\alpha$  glucosidase.  $\alpha$  galactosidase hydrolyze melibiose and  $\beta$  galactosidase hydrolyze lactose.
- **Polysaccharides** : Starch is broken down to maltose and glycogen to glucose by the action of an amylase which specially catalyzes the hydrolysis of 1-4  $\alpha$  glucosidic linkages in polysaccharides
- There are two types of amylases
  - ▣ **Exoamylases** : It splits maltose residues from the ends of the starch molecule leading to a rapid increase in the concentration of maltose.
  - ▣ **Endoamylase** : It attacks bonds well with in the starch molecule so that there is only a slow build of maltose to start with. The products are then further digested in the normal way by  $\alpha$  glucosidases.

Although many insects feed on plants and wood, only minority of them have cellulase enzyme capable of hydrolyzing cellulose. Where there is no cellulase the insects must either feed on the cell contents without digesting the cell walls or they must rely on microorganisms to digest the cellulose for them.

Ex: Lyctids and scolytids have no cellulase. Anobiidae and cerambycidae have cellulase.

Cellulase acts by breaking cellulose down into cellobiose units, which are further hydrolyzed by a  $\beta$  glucosidase. Larval scarabaeiodes have no cellulase they feed on rotten wood and it is digested by bacteria. In some other wood eating insects there is a permanent gut flora or fauna concerned with cellulose digestion.

## 2. Proteins

Insects possess a series of proteases. A trypsin like proteinase which breaks down protein to peptones and polypeptides are produced in the midgut. These in turn are acted on by peptidases. But most of the polypeptides are absorbed before being further digested.

There are different types of peptidases

**Carboxypolypeptidases:** These attack the chain from  $-\text{NH}_2$  end and dipeptidases hydrolyse all dipeptides.

Some insects are able to digest the inert animal proteins, such as keratin and collagen. Keratin is the protein found in wool, hair and feathers. It consists of polypeptide chains including sulphur containing amino acids which are linked together by sulphide bonds rendering the whole protein stable. Ex: Mallophaga of birds and dermestid larvae.

## 3. Lipids

Lipid is usually ingested mainly in the form of triglycerides. Digestion involves the production of smaller molecules of diglycerides, monoglycerides and free fatty acids. These are 3 types

**a). Lipases :** These cleave insoluble glycerides of long chain fatty acids.

**b). Esterases :** These act on glycerides of short acids.

**c). Phosphatases :** These help in digestion of phospholipids.

A specialized case of lipid digestion is the digestion of bee wax by larvae of the wax moth *Galleria*. Though the insect produces lipase, lecithinase and cholinesterase, most of digestion of the esters and fatty acids results from the activities of the bacteria.

### 3.6 CIRCULATORY SYSTEM

Insects have open blood system with the blood occupying the general body cavity known as hemocoel.

Blood is circulated by the contraction of dorsal longitudinal vessel which opens into the hemocoel.

The circulatory organs of the insect are

1. Dorsal vessel
2. Dorsal and ventral diaphragms
3. Accessory pulsatile organs

#### 1. Dorsal vessel

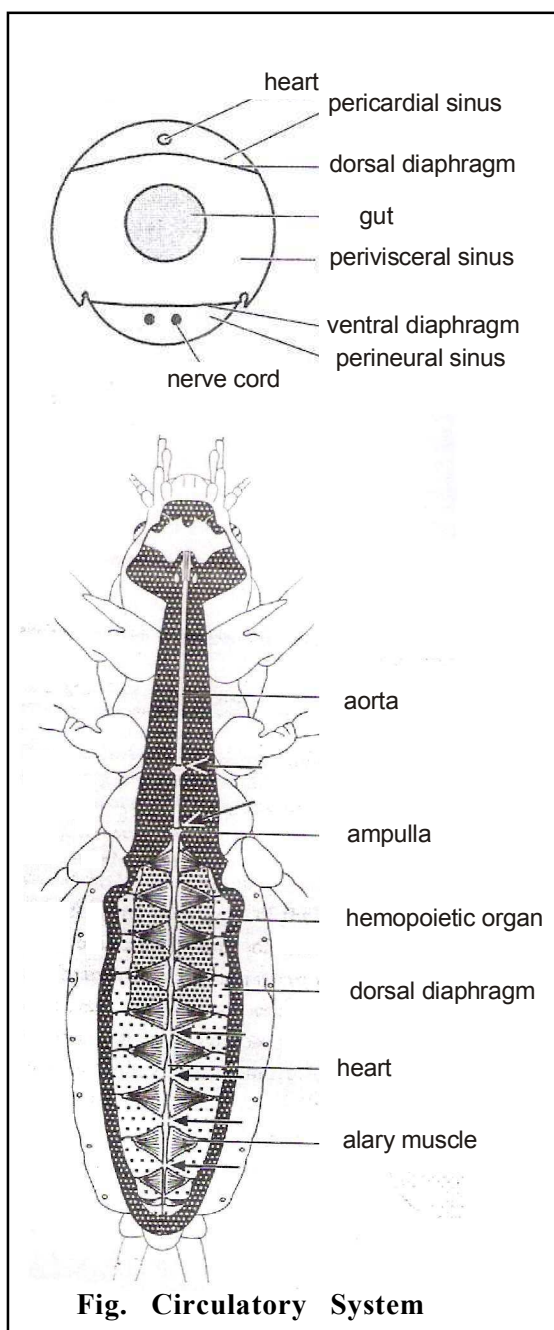
It is a continuous tube whose posterior end is closed and anterior end is open. The dorsal vessel is divided into two regions

- a). A posterior heart
- b). An anterior aorta

Heart acts as pumping organ and aorta acts as conducting vessel.

#### a). Heart

It runs as slender tube slightly swollen at each segment, closely attached to ventral side of the terga. The posterior end of the tube is closed. It may be divided into a series of chambers by successive constrictions and the number of chambers varies in different insects. Every swollen portion of heart is called as ventricle, the posterior portion of which is divided into three lobes, one dorsal and two lateral. A slit like opening is found at base of each lateral lobe, which is known as ostium, through which



**Fig. Circulatory System**

the blood from hemocoel enters the heart. Each ostium is provided with an ostial valve which permits the blood into heart but does not allow it to go back into the hemocoel. Posterior heart is perforated by incurrent and excurrent openings (ostia).

- **Incurrent ostia**

The incurrent ostia are vertical, slit like openings in the lateral wall of the heart. The anterior and posterior lips of each ostium are reflexed into the heart to form a valve which permits the flow of blood into the heart at diastole, but prevents its outward passage at systole. During diastole the lips are forced apart by the inflowing blood. When the diastole is complete the lips are forced together by the pressure of blood in the heart and they remain closed through out the systole.

- **Excurrent ostia**

Externally each opening is surrounded by a papilla of spongiform multinucleate cells which expands during systole, so that hemolymph is force out and contracts during diastole so that entry of blood is prevented.

**b). Aorta**

It is the anterior prolongation of the dorsal vessel. It is simple tube which extends from the first abdominal segment to head where it opens near the brain. It function as principal artery of the body.

**2. Dorsal and ventral diaphragms**

- **Dorsal diaphragm** : It extends across the abdominal cavity above the alimentary canal and the blood space enclosed by this is known as dorsal or pericardial sinus which contains heart. The dorsal diaphragm is fenestrated connective tissue membrane. It is usually incomplete laterally, so that the pericardial sinus above it is broadly continuous with the perivisceral sinus below. The lateral limit of the diaphragm are indefinite and are determine by the presence of muscle, trachea or the origins of the alary muscles which form an integral part of the diaphragm. Pair of alary muscles arise from terga and spread out fan wise over the surface to the dorsal diaphragm.
- **Ventral diaphragm** : The ventral diaphragm is horizontal septum just above the nerve cord cutting off the perineural sinus from the main periviscerals sinus and blood space enclosed by this is known as ventral or peri neural sinus.  
Both dorsal and ventral diaphragms divide the hemocoel into 3 sinuses
  1. Dorsal or pericardial sinus
  2. Middle or perivisceral sinus
  3. Ventral or perineural sinus



Dorsal or pericardial sinus is the upper chamber in which heart and aorta are situated. Middle or perivisceral sinus is the middle chamber where alimentary canal is situated. Ventral or perineural sinus is situated beneath the ventral diaphragm in which nervous system is located.

### 3. Accessory pulsatile organs

These are sac like structures situated in various regions of the body and pulsate independently of the heart, ensuring adequate circulation of blood through appendages. A pulsatile organ drawing blood from the wings is present in both wing-bearing segment of most adult insects.

When the muscle contract, the ampulla is compressed and blood is driven into the aorta. At the same time the volume of the subscutellar reservoir is increased and blood is drawn from the wings. When the muscles relax, the elastic ligaments restore the shape of the ampulla so that the blood is sucked into it from the reservoir.

A pulsatile organ is also found at the base of each antenna. It consists of an ampulla from which a fine tube extends almost to the tip of antenna. Compression of dilator muscles of ampulla drives hemolymph into the antenna.

## ■ Blood

The blood of the insect is called haemolymph. It is rich in trehalose and non protein nitrogen. It consists of plasma liquid and blood cells or haemocytes.

**Plasma** : It consists of 85% water. It is slightly acidic and includes inorganic ions, amino acids, proteins, fats, sugars and organic substances in variable amounts.

### The various functions of plasma involves

- Storage of water and food
- Transportation of food materials and hormones
- Mechanical functioning of eversion of protrusible structures
- Amino acids and proteins are stored and reused when need arises
- Respiratory role as in *Chironomid* larvae
- Reflex bleeding

## ■ Haemocytes

There are 4 types of haemocytes

### 1. Prohaemocytes

Small, rounded with basophilic cytoplasm. They divide and give rise to other types of haemocytes.

**2. Plasmatocytes**

They have basophilic cytoplasm with ribosomes and mitochondria. They are phagocytic in nature.

**3. Granular haemocytes**

They have acidophilic granules with rough endoplasmic reticulum. They are phagocytic in nature.

**4. Cystocytes or coagulocytes**

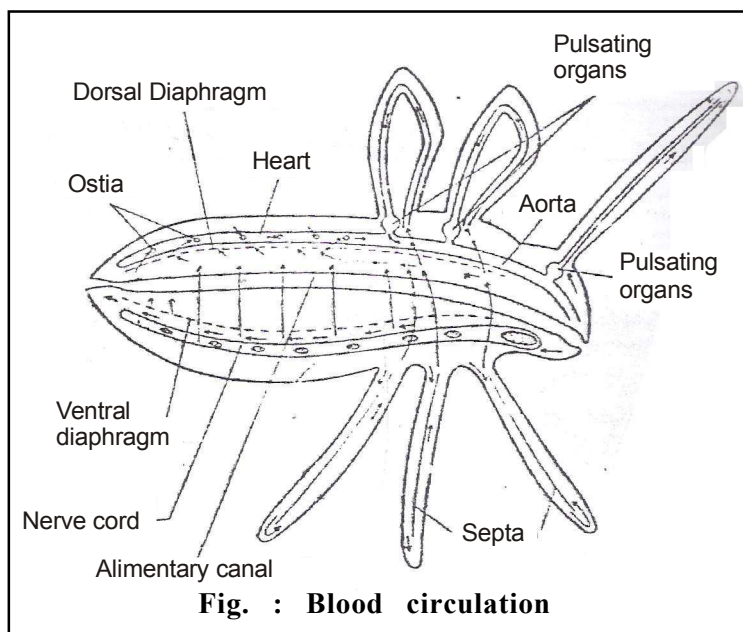
They have hyaline cytoplasm with nucleus and scattered granules. These are specialized granular haemocytes and they help in coagulation.

***Functions of haemocytes***

- Phagocytosis of foreign particles, micro-organisms and tissues debris
- Encapsulation of such organisms which are too large for phagocytes
- Hemocytes are concerned in the formation of connective tissues
- They are also involved in the formation of fat bodies and are concerned in intermediate metabolism
- Wound healing and coagulation

**■ Blood circulation**

In normal circulation, the blood is pumped forwards through the heart at systole passing out of the heart via the excurrent ostia and anteriorly from the aorta. The valves of incurrent ostia prevent the escape of blood through these openings. The blood driven forward by the heart increases the blood pressure anteriorly in the perivisceral sinus so that in this sinus blood tends to pass backward along a pressure gradient. From the perivisceral sinus the blood percolated down to the perineural sinus where the movement of the ventral diaphragm



**Fig. : Blood circulation**

assists the backward flow of blood. The contraction of alary muscles tends to flatten the dorsal diaphragm. This flattening increases the volume of pericardial sinus at the expense of perivisceral sinus. As a result the blood passes into pericardial sinus and then at diastole it is drawn in to the heart through the incurrent ostia.

### ■ Heart beat

It is of 3 phases

- i). Systole : Contraction of muscles of heart wall which starts posteriorly and spreads forward.
- ii). Diastole : Relaxation of muscles of the heart.
- iii). Diastasis : The heart rest in expanded condition this phase is called diastasis.

Control of heart beat is neurogenic when there is supply of nerves and when the nerve supply is cut off it is myogenic.

## 3.7 RESPIRATORY SYSTEM

### ■ Respiration

It is a process of interchange of gases between the environment and the blood or cellular tissues of the organism. It includes both chemical and physical phases. The chemical phase is concerned with oxidation in the body tissues resulting in the formation of carbon dioxide and water. The physical phase involves transportation of air to tissues and elimination of carbon dioxide. The special mechanical devices that are developed to facilitate the respiration in animals constitute the respiratory system.

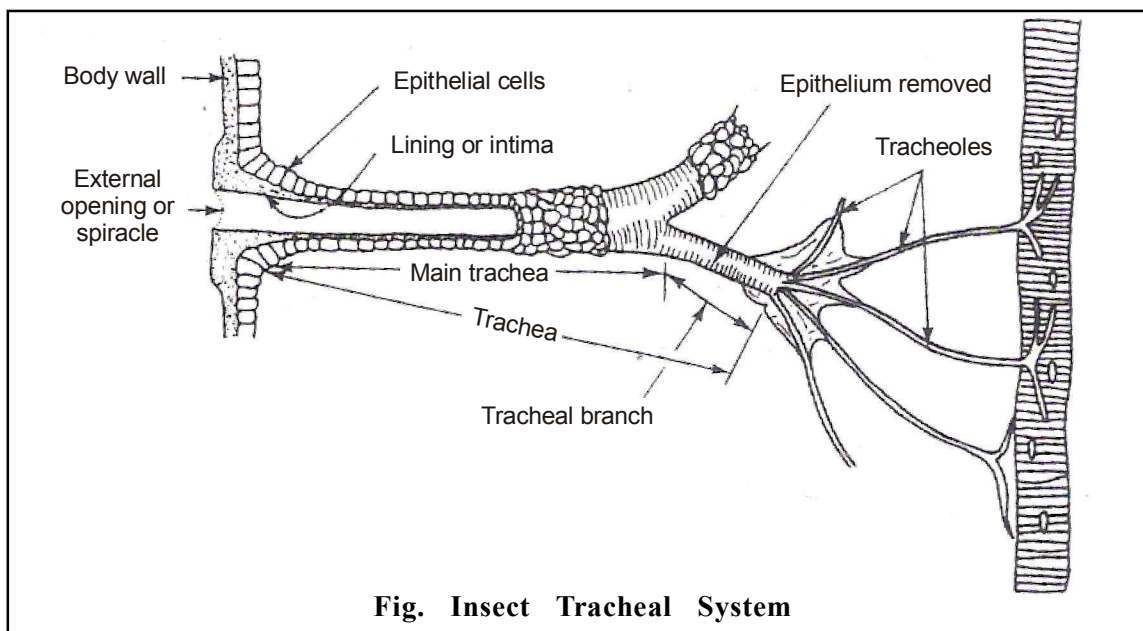
The main respiratory organs in insects are trachea

#### • Tracheal respiration

The trachea are ectodermal in origin and are tubular invagination of the body wall. The trachea present a ringed appearance due to thickening of intima known as taenidia. The taenidia prevent the collapse of trachea if the pressure within is reduced. The trachea divide and re divide into smaller branches known as tracheoles. The tracheoles are less than 2 microns and are lined by taenidia. The base of each cluster of tracheoles has a web like cell known as end cell or tracheole cell which lie within the tissue cells of the body.

The trachea from neighbouring spiracles join to form longitudinal trunks running along the length of the body. There are lateral trunks in addition to the dorsal and ventral longitudinal trunks. The longitudinal trachea are connected to each other

by transverse commissures. The trachea has direct contact with air and with the tissues through a number of openings known as spiracles.



**Fig. Insect Tracheal System**

- **Spiracles**

These are present on the pleura of the thoracic and abdominal segments or between the terga and sterna. According to number and arrangement of functional spiracles respiratory system is of 3 types

- |                |                  |               |
|----------------|------------------|---------------|
| I. Polyneustic | II. Oligoneustic | III. Aneustic |
|----------------|------------------|---------------|

- I. Polyneustic**

At least 8 functional spiracles on each side of the body. It is further divided into

- Holopneustic** : Ten pairs of spiracles, 1 mesothoracic, 1 meta thoracic and 8 on first eight abdominal segments.  
Ex : Diptera and Hymenoptera
- Perineustic** : Nine pairs of spiracles, 1 mesothoracic and 8 abdominal spiracles are functional.  
Ex : Cecidomyid larvae
- Hemipneustic** : Eight pairs of spiracles, 1 mesothoracic and 7 abdominal spiracles are functional.  
Ex : Neuroptera and Lepidoptera

## II. Oligoneustic

There are 1 or 2 functional spiracles on each side of the body. It is further classified as

- a) **Amphipneustic** : 2 pairs of spiracles. One mesothorax and one posterior abdominal spiracle are open  
Ex : Larval Diptera
- b) **Propneustic** : Only one pair of spiracles open on mesothorax  
Ex : Dipteran pupae
- c) **Metapneustic** : Only one pair of abdominal spiracles is open  
Ex : Larval Diptera

## III. Apneustic

None of the spiracles are open

Ex : Collembola, Protura, parasitic Diptera and Hymenoptera

Spiracles are hydrophobic i.e. their surface resists entry of water. The hydrophobic condition is created by oily substances which is secreted by peristigmatic glands situated close to spiracles. In many winged insects the tracheae are dilated in various parts of the body to form thin walled vesicles or air sacs. These are well developed in swift flying insects and help them in lowering of specific gravity which makes easier the flight of large species. The main function is to give an increased ventilation i.e large amount of air can be inspired and expired during respiratory movements

- **Integumental respiration**

Insects which do not have trachea the exchange of gases takes place directly through the integument.

Ex : Collembola, Protura, aquatic Chironomidae and parasitic larvae

- **Blood gills**

These are tubular in shape. These contain blood and help in the absorption of water and inorganic ions rather than respiration.

Ex : Larval Trichoptera, Diptera and well developed in the larvae of *Chironomus*

- **Respiration process**

Respiration occurs by the diffusion of oxygen and carbon dioxide through the tracheal system, aided by the mechanical ventilation of abdominal trachea and air sacs.

Diffusion of oxygen into the system is triggered by a drop in oxygen pressure at the tip of tracheoles.

- **Pneumatization**

The tracheal system is liquid filled in a newly hatched insect. The liquid is replaced by gas by a process known as pneumatization. When the metabolic rate is high, osmotic pressure rises and fluid is with drawn from the tracheoles. When it is low osmotic pressure falls and capillarity draws fluid into the tracheoles.

- **Gaseous exchange in terrestrial insects**

The important function of respiratory system is gaseous exchange, take up of oxygen and give out carbon dioxide.

The 2 distinct phases involved in gaseous exchange are

1. Air tube diffusion (through tracheal system)
2. Tissue diffusion (tissue in solution in cytoplasm)

The gas enters the spiracles by diffusion due to the difference in gradient. Transport of gases through tracheal system is called air tube diffusion and transport of gases through tissues in solution in the cytoplasm is called tissue diffusion.

## ■ Diffusion

Diffusion of gas depends on molecular weight of gas, difference in concentration of the gases at two ends. Oxygen in air diffuses 100,000 times faster than in water or the tissues, hence the path of oxygen through the tracheal system is very longer than its path through tissues. Carbon dioxide permeability in water is 36 times greater than oxygen hence its movement in tissues is more. Carbon dioxide is present in higher concentrations in the tissues than oxygen. It is retained in the hemolymph before diffusion into the trachea near the spiracles or passes out directly through the integument.

In addition to diffusion ventilation is also required for the supply of sufficient oxygen. Changes in the volume of tracheal system are called ventilation. In majority of the insect's large changes of volume is brought about by altering collapse and expansion of air sacs.

There are 3 phases

1. Inspiration phase (20 % of the cycle)
2. Compression phase
3. Expiration phase (5 - 10 % of the cycle)

Compression of system by the tergum and sternal muscles leads to the decrease

in volume. Various organs present in the body press the air due to the increase in blood pressure and causes the air to move out. This is expiratory phase. Relaxation of muscles and reduction of pressure due to the muscular or elastic expansion of the abdomen leads to inspiration phase. The insect is kept in compensatory phase for some time and it is known as compensatory condition. This allows the movement of air in and out the spiracles. Air flow in and out of the spiracles and such movement of air is called tidal flow. The air enters through the spiracles in the anterior region and expelled through the spiracles in the posterior region. Hence there is no dead air. The abdomen starts to contract while the spiracles are still closed so that the air in the trachea is under pressure. This is known as compression phase. Then the expiratory spiracles open and air is forced out.

- **Gaseous exchange in aquatic insects**

Aquatic insects obtain oxygen directly from the air or from the dissolved oxygen from water.

- **Oxygen from the air**

Insects acquiring oxygen from air make frequent visits to the surface of the water. These insects have to prevent the entry of water into the spiracles during submergence. This is achieved by possessing hydrofuge properties around the spiracles or production of an oily secretion by perispiracular glands in and around the spiracle. In *Notonecta* (Heteroptera) hydrofuge properties round the spiracles are associated with hairs which close when the insect enters the water and open at surface of being spread out by surface tension. Some insects have semi-permanent connection with the air that enables them to remain submerged in water.

Ex: Larvae of hover fly, *Eristalis* (Diptera)

It has a telescopic terminal siphon of 6 cm length with which it acquires air from the water surface from water bottom.

Some insects obtain oxygen by thrusting their spiracles into the aerenchyma of aquatic plants. Ex: *Chrysogaster* and *Notiphila* (Diptera)

Some insects have an extra tracheal air store. They carry a bubble of air and spiracles open into this bubble. It provides continuous air supply to tracheal system when the insect is in submerged condition. Ex: Mosquito larvae

- **Oxygen from water**

In insects which obtain oxygen from water the gaseous exchange with water takes place through thin walled gills well supplied with tracheae or in some insects thin permanent film of air is present on the outside of the body. Many larval forms of aquatic insects depend on cutaneous respiration. Cuticle must be thin and permeable to oxygen and highly developed trachea and tracheoles net work is present beneath the cuticle.

- **Gaseous Plastron**

There is permanent thin layer of air known as gaseous plastron held by various means around the body surface. These contain hydrofuge devices like hairs which are closely spaced together so that water under normal pressure can not enter these. The spiracles are situated just below the plastron layer but air itself does not enter the trachea. The plastron acts as physical gill through which the dissolved oxygen from the water enters the plastron and diffuse into insect system

Ex: Eggs and pupae of aquatic insects

- **Tracheal gills**

These are present on abdomen. These are filiform in shape well supplied with trachea and tracheoles. The exchange of gases takes place through these.

Ex: Aquatic larvae

- **Spiracular gills**

These are extensions of spiracles or the cuticle surrounding them to form long, partly hollow process. These help in both aquatic as well as aerial respiration. In water the film of air forms a gas water interface for diffusion, and in air the interstices of gill provide a direct route for entry of oxygen.

Ex: Pupae of beetles and Diptera

- **Gaseous exchange in endo - parasitic insects**

Endo - parasitic insects obtain oxygen directly from the air outside the host or by diffusion through the cuticle from the surrounding host tissues.

Ex : Ichneumonid and braconid larvae

***Other functions of tracheal system***

- The air sacs help in lowering the specific gravity and provide buoyancy in aquatic insects
- The tracheal system play an important role in hemolymph circulation
- The air sacs permit changes in gut volume as a result of feeding
- The trachea form a reflexing tapetum beneath the eye in Noctuids
- Tympanal organs are backed by air sacs which allow the tympanum to vibrate freely
- The tracheal system act as connective tissue, binding other organs together
- Tracheal system also help in the defense of the insects by production of quinones or by producing sound by forcing air into the spiracles



### 3.8 REPRODUCTIVE SYSTEM

#### ■ Male reproductive system

The male reproductive system consists of

1. A pair of testes
2. A pair of vasa deferentia
3. Seminal vesicle
4. The ejaculatory duct
5. Accessory glands

**1. The testes :** They are anteriorly attached to the dorsal body wall and posteriorly open into the vasa deferentia. They are externally covered with fat body and richly supplied with tracheae. The size and shape vary in different insects.

**2. Vasa deferentia :** It receives sperms from the testes and facilitate their transport to the ejaculatory duct.

**3. Seminal vesicle :** Each vasa deferentia becomes enlarged to form a sac known as seminal vesicle in which sperms are stored.

**4. The ejaculatory duct :** It is ectodermal in origin and epithelium lined with cuticle. Both the vasa deferentia open distally into the median ejaculatory duct.

**5. Accessory glands :** They occur from one to 4 pairs.

These are of 2 types

- a. **Ectadenia :** These are ectodermal in origin and they open into ejaculatory duct. They occur in Coleoptera.
- b. **Mesadenia :** These are mesodermal in origin and they open into vasa deferentia, seminal vesicle or ejaculatory duct. They occur in Orthoptera

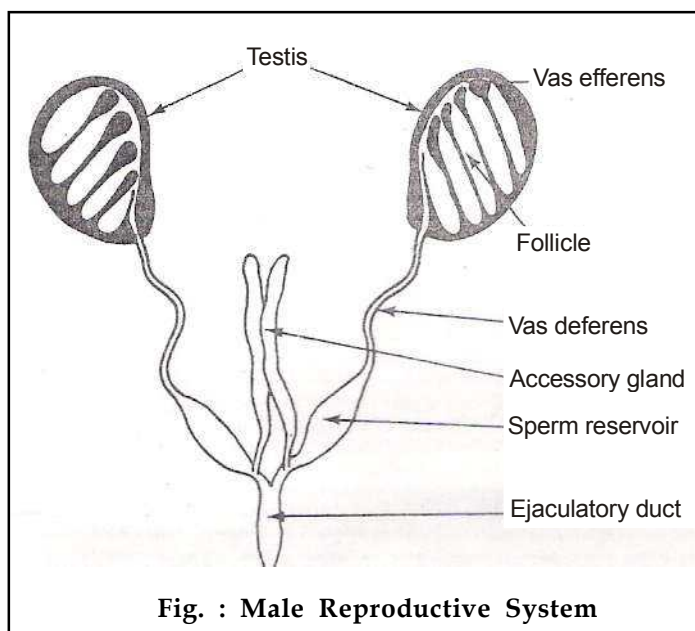


Fig. : Male Reproductive System

### ■ Female reproductive system

It consists of

1. A pair of ovaries
2. A pair of lateral oviducts
3. A median oviduct
4. A spermatheca
5. Vagina or genital chamber
6. Accessory glands

1. **Ovaries:** The functional unit of ovary is called ovarioles. They are enclosed in outer layer called, tunica externa and inner layer, called tunica propria. The number of ovarioles varies in different species of insects.

Each ovariole is differentiated into 4 regions. They are

- a. The Terminal filament
- b. The Germarium
- c. The Vitellarium
- d. The Pedicel

- a. **Terminal Filament** : It is an apical prolongation and contains a mass of nuclei with scanty cytoplasm.
- b. **The Germarium** : It is the most active site of the oogenesis. It contains primordial germ cell, prefollicular cells and nutritive cells.
- c. **The Vitellarium** : It is site of vitellogenesis. It is the largest part of the ovariole and is characterized by large number of growing oocytes in liner fashion. The oocyte development takes place and fully grown ova are provided with two membranes, outer chorion and inner vitelline.
- d. **The Pedicel** : It is the stalk of the ovariole and provides passage to the ova from the vitellarium to the lateral oviduct.

2. **The lateral oviducts** : These are oviducts are paired long tubular canals leading from the ovaries and are formed from the mesoderm. Each oviduct is an enlarged pouch which stores eggs.

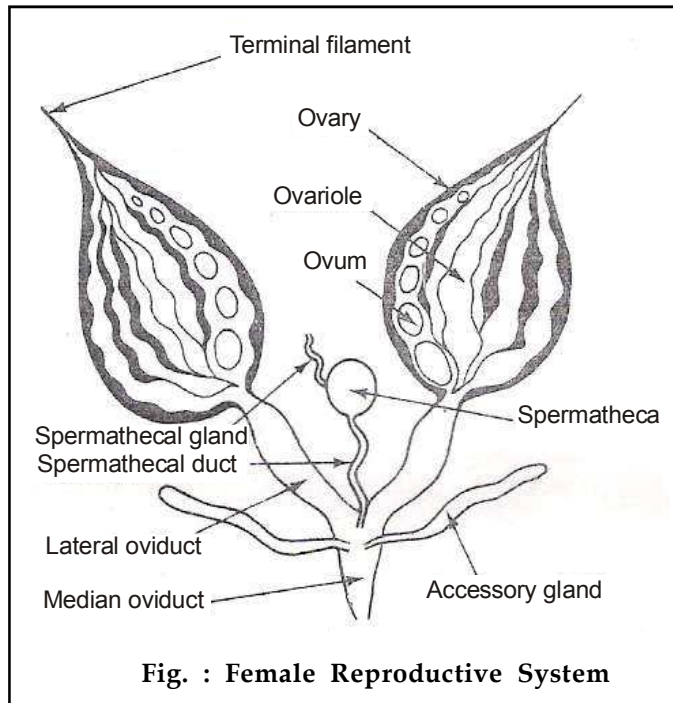


Fig. : Female Reproductive System

3. **The median oviduct** : It is ectodermal in origin and lined with cuticle. It is a short but broad duct receiving anteriorly the lateral oviduct.
4. **The spermatheca** : It is ectodermal in origin and formed as an invagination of the 8<sup>th</sup> sternite. The number, size and shape vary in different insects. The spermathecal epithelium secretes nutrients for the sperms stored in spermatheca. The spermathecal duct opens into genital chamber. The spermatozoa are stored in the spermatheca of the female.
5. **Vagina or genital chamber** : The posterior part of median oviduct is modified into a sac like structure known as vagina or genital chamber. The vagina opens outside by vulva. The vagina is well developed to form a pouch, the bursa copulatrix which receive the penis.
6. **Accessory glands** : They secrete material used in the synthesis of the egg coat, and hence called as collateral glands. The accessory glands secrete frothy secretions forming egg pods in grasshoppers.

### 3.9 NERVOUS SYSTEM

The nervous system in insects consists of large number of nerve cells called neurons.

- **Neuron** : Each neuron consists of a cell body or perikaryon with a nucleus and protoplasmic extensions. The longest protoplasmic extension arising from perikaryon is called as axon, while the shorter ones are known as dendrites. The axon gives out as side branch known as collaterals near its origin from the cell body. Axons, collaterals and dendrites distally divide into fine fibrils called terminal arborisations. An aggregation of neurons forms a ganglion and collection of several neuronic strands forms a nerve.
- **Glial cells** : Each neuron is covered by one or more glial cells. They form an insulating and protecting sheath around neuron. The narrow spaces between glial folds show periodic lacunae, which are the characteristic of insect nerves. The glial cells also pass nutrients to neuron by glial lacunae system. Glial processes are connected to each other by desmosomes, tight junctions and gap junctions.
- **Nerve sheath** : The entire nervous system is separated from hemolymph by nerve sheath. It has two layers. An outer one is non cellular layer called neural lamella and inner cellular layer called perineurium. Perineurium cells contain abundant mitochondria and serve as store house of glycogen. The neural lamella is secreted by cells of the perineurium. It provides mechanical support to the nervous system.

**There are 3 types of neurons**

1. **Sensory neurons** : These are also known as afferent neurons and are concerned with the perception of the stimuli and conducting them from the site of perception to central nervous system.
2. **Motor neurons** : These are also known as efferent neurons. These are responsible for conducting impulse's from the central nervous system to muscles.
3. **Internuncial neurons** : These neurons link the sensory neutrons with the motor neurons within central nervous system through synapse.

■ **Nervous system**

The nervous system of insects function to generate and transport electrical impulses, to integrate information receive, and to stimulate muscles for movement.

The nervous system of insects consists of 3 parts

- I. Central nervous system
- II. Visceral or stomato-gastric or sympathetic nervous system
- III. Peripheral nervous system

**I. Central nervous system**

The central nervous system can be distinguished into 3 regions

1. Brain or cerebral ganglion or supra oesophageal ganglion
2. Sub oesophageal ganglion
3. Ventral nerve cord

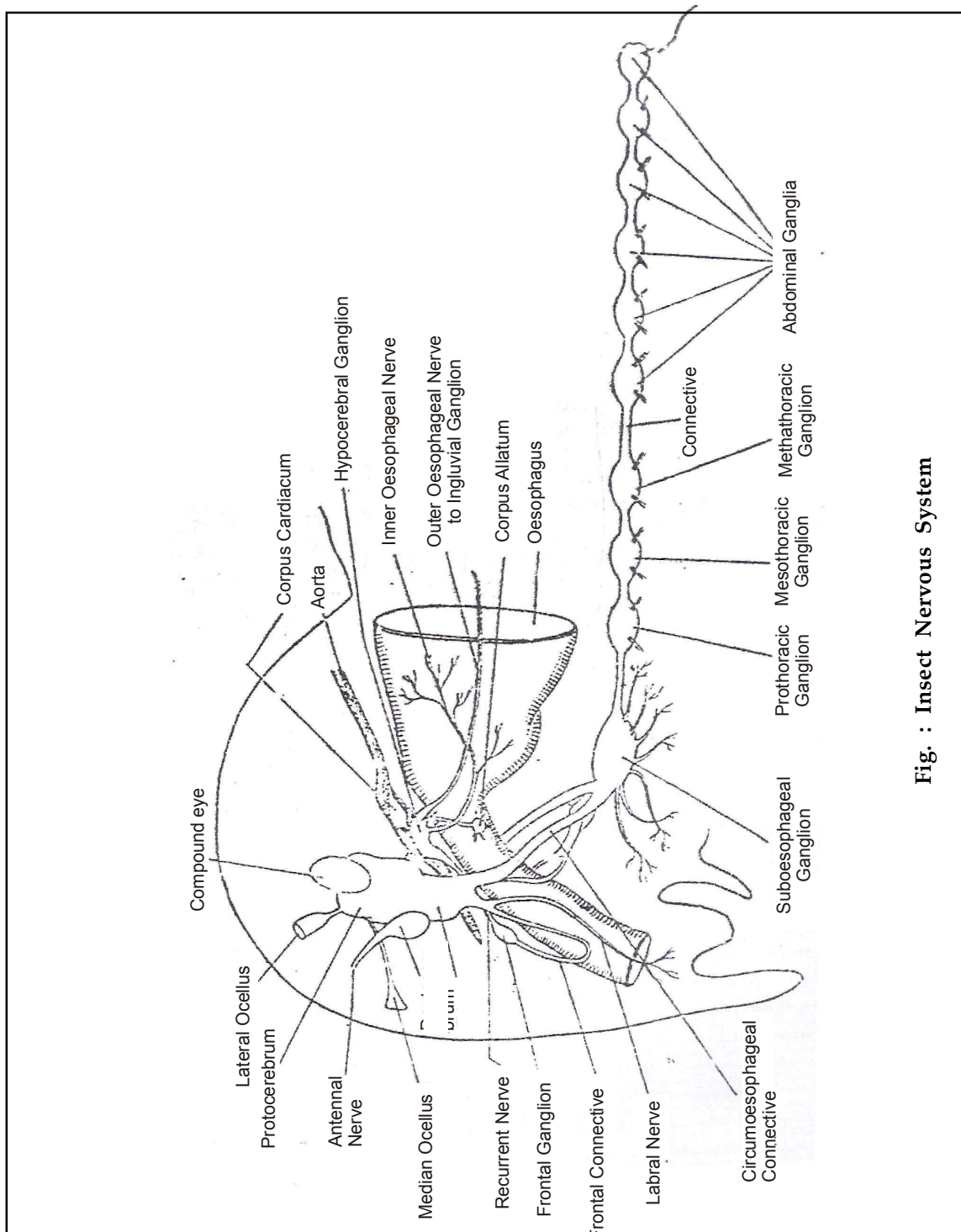


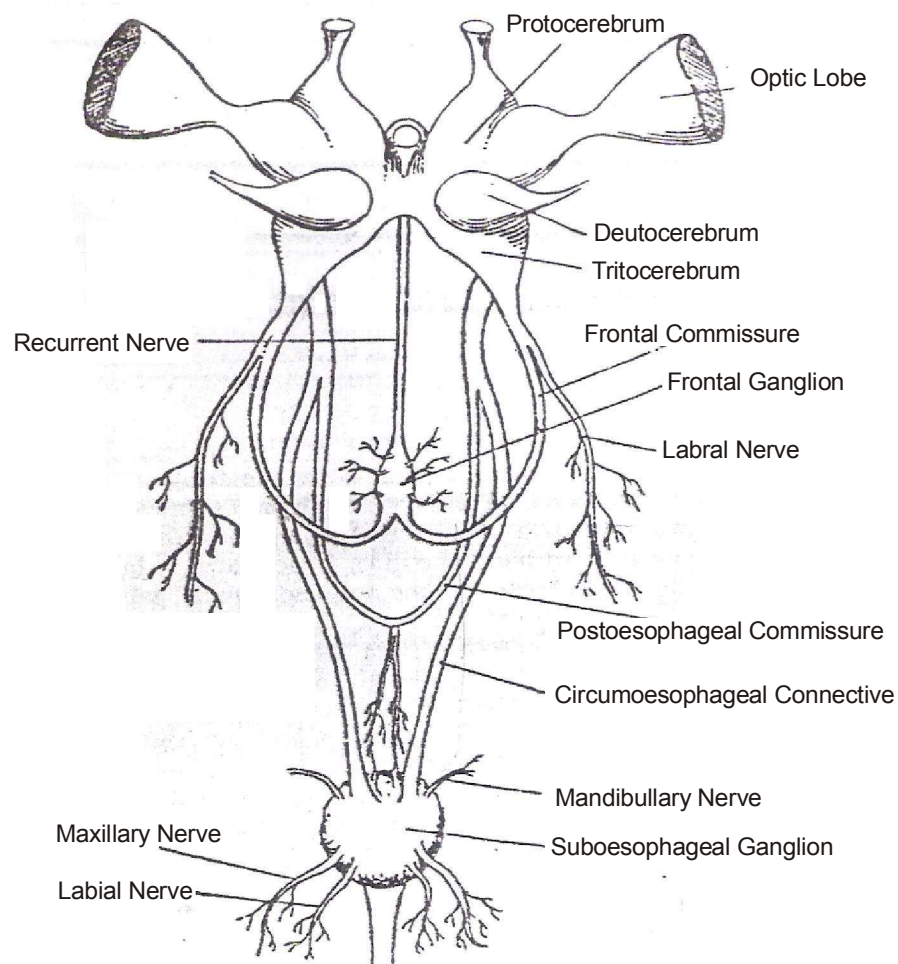
Fig. : Insect Nervous System

## 1. Brain

It represents the supra oesophageal ganglion and it lies above oesophagus in the occulo frontal region of the head. It is a bilobed structure.

It is divided into 3 regions. They are

- i. Fore brain or protocerebrum
- ii. Midbrain or deutocerebrum
- iii. Hind brain or tritocerebrum



**Fig. : Brain**

- i. **Protocerebrum** : It represent fused paired preantennal ganglia. It supplies nerves to compound eyes and ocelli. On each lateral side it bears optic lobe which receives optic nerves, the ocellar nerves form medina and lateral ocelli and it give out cardiac nerves innervating the corpora cardiaca and the aorta.
- ii. **Deutocerebrum** : It represents antennal ganglia. It gives out a pair of lateral antennal nerves innervating the antennae.
- iii. **Tritocerebrum** : It represent the intercalary segment ganglia. It gives out nerves which innervate labrum and the frontal connective terminating into the frontal ganglion.

The tritocerbral lobes are connected with the suboesophageal ganglion by the circumoesophageal connectives.

## 2. Sub oesophageal ganglion

It is formed by the fusion of ganglia of the mandibular, maxillary and labial segments. It lies below the oesophagus and posterior to the brain. Nerves from this innervate mandibles, maxillae, hypopharynx, labium and neck.

## 3. Ventral nerve cord

It consist of three thoracic ganglia of thoracic region and five or six abdomen ganglia of abdominal region. The nerves arising from prothoracic ganglion innervate leg muscles. The meso thoracic and meta thoracic ganglia gives off nerves which innervates wings.

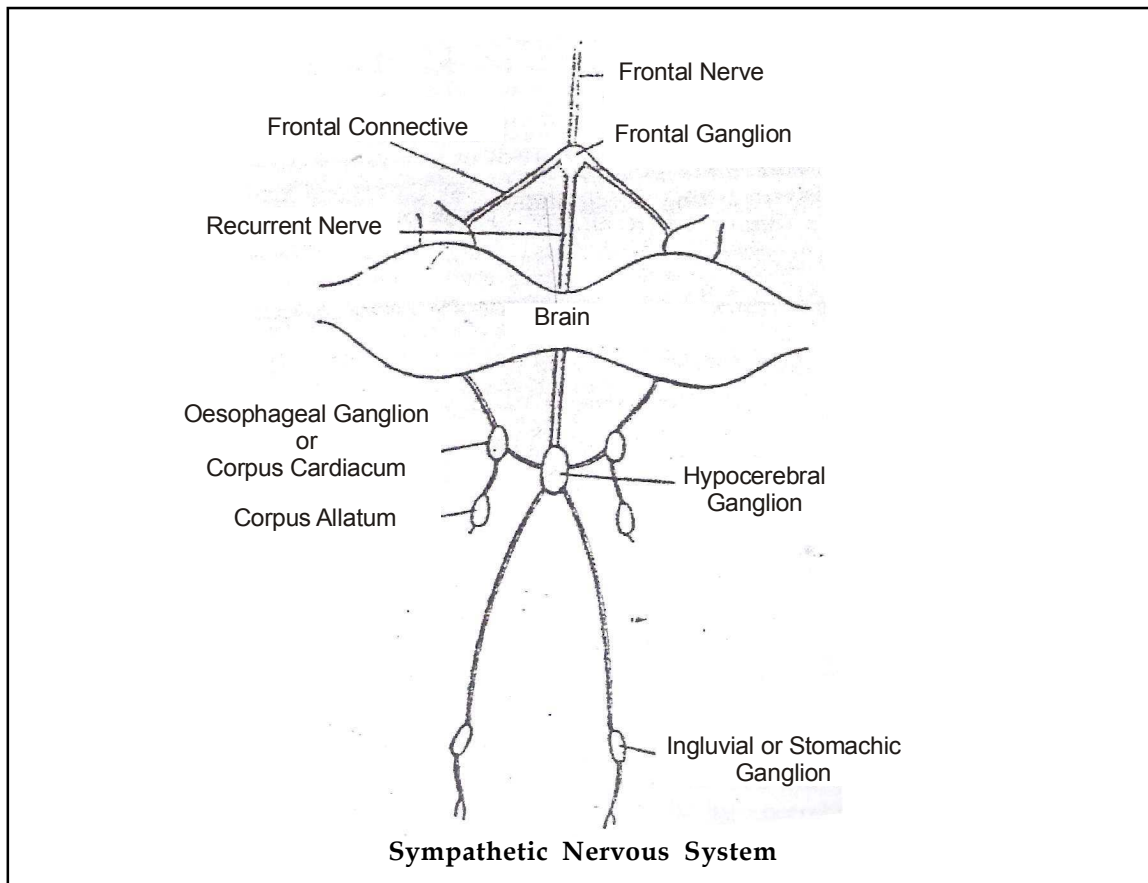
The number of abdominal ganglia varies in different insects. The nerves arising from these ganglia innervate, muscles of abdominal segments, epiprocts, paraprocts, cerci and rectum. In some families of Diptera and Hemiptera all the thoracic and abdominal ganglia fuse in to single mass located in the thorax.

## II. The sympathetic nervous system

It is divided into

- a. Anterior sympathetic nervous system
  - b. Posterior sympathetic nervous system
  - c. Caudal sympathetic nervous system
- a. **Anterior sympathetic nervous system**: It is also called as stomatogastric or stomodeal nervous system. It contains frontal, hypocerebral and ventricular ganglia, along median recurrent nerve and other fine nerves arising from these ganglia. It innervates mainly stomodeum and the dorsal vessel.
  - b. **Posterior sympathetic nervous system**: It is also called as ventral sympathetic nervous system. From each ganglion of the ventral nerve cord arise medial nerve





which terminally gives off a pair of transverse nerves. These innervate the spiracles, segmental and alary muscles.

- c. **Caudal sympathetic nervous system** : The last abdominal ganglion gives off the caudal sympathetic nervous system. The nerves innervate the reproductive system, hind gut, Malpighian tubules and the caudal part of the dorsal vessel.

### III. Peripheral nervous system

It consists of nerves radiating from ganglia of central and sympathetic nervous systems. The axons of the sensory neurons of receptors run from periphery of the insect inwards to central nervous system while the axon of the motor neurons go out ward to muscles and glands from central nervous system.

#### Nerve impulse transmission is of two types

1. Conduction of nerve impulse in axons
2. Synaptic conduction / biochemical conduction



### 1. Conduction of nerve impulse in axons

Nerve impulses along the axon are resulted due to the changes in the conductance of the membrane to  $\text{Na}^+$  and  $\text{K}^+$  ions.

- **Resting potential:** During the resting state of axon, there is an excess of  $\text{Na}^+$  ions external to the membrane and excess of  $\text{K}^+$  ions in the axon cytoplasm. A Donnan equilibrium is set up across the plasma membrane with a high concentration of  $\text{K}^+$  ions inside and high concentration of Chloride ( $\text{Cl}^-$ ) ions outside. As a result of the equilibrium the charge inside of the axon becomes -vely charged with respect to the outside and the potential produced in this way is known as resting potential. Normally insect nerve axons have a resting potential of about -70 mv.
- **Action potential :** Generator potential produces changes in the permeability and leads to action potential. In membrane depolarization which resulted due to the opening of the ionic channels of the post synaptic receptors due to binding of the transmitter molecules at the chemical synapse, the membrane becomes more permeability to  $\text{Na}^+$  ions, as a result of which  $\text{Na}^+$  ions flow into the axon. This produces +ve charge inside the membrane. This represents the rising phase of the action potential. Adjacent areas of axon are -vely charged, so a current flows in a local circuit away from the point of depolarization. When this current reaches an area of resting membrane it produces depolarisation. It causes the increase in the permeability to  $\text{Na}^+$ , producing +ve charge inside the membrane. In this way a wave of increased permeability, and hence, a nerve impulse is propagated along the axon.

### 2. Synaptic conduction/biochemical conduction

The branched terminal of the axon of one neuron comes in intimate association with the collateral or terminal arborizations of another neuron to form a synapse. The gap between them is of about 100 Å.

Arrival of the electrical/nerve action potential at the axon terminal causes the liberation of acetyl choline, a neurotransmitter substance which diffuses across the synaptic cleft. The acetyl choline is present in vesicles in presynapse is positively charged. As the axonic conduction reaches the presynapse the acetyl choline which is in inactivated state gets activated and moves towards the post synapse stage and it is liberated with movement of nerve impulses. It combines with a receptor protein to bring about a localized depolarization. Proper ionic concentration of extracellular  $\text{Ca}^{++}$  ions is necessary which activates the discharge of the contents of the vesicle to the exterior. The pre synaptic depolarization increases the permeability of the membrane to calcium. The calcium ions diffuse into the pre synaptic terminal due to its concentration gradient. It facilitates the fusion of vesicles and presynaptic membranes at specific release sites. Once the impulse has been

triggered at the post synaptic region, acetyl choline is broken down in to acetic acid and choline by the enzyme, acetyl cholinesterase. Acetyl choline is re synthesized in the at special sites in pre synaptic area in presence of another enzyme, choline acetylase.

### 3.10 EXCRETORY SYSTEM

#### ■ Excretory system

The process of elimination of waste products is called as excretion and the organs associated with this process constitute the excretory system.

The main excretory organs in insects are

- |                             |                  |
|-----------------------------|------------------|
| 1. Malpighian tubules       | 2. Integument    |
| 3. Wall of alimentary canal | 4. Labial glands |
| 5. Nephrocytes              | 6. Fat bodies    |
| 7. Oenocytes                |                  |

#### 1. Malpighian tubules

The Malpighian tubules were first discovered by an Italian anatomist Malpighi and were named after him. These are long slender tubules lying in the hemocoel. These open at their proximal extremities into the intestine, near the junction of hindgut and midgut. Distally these are free but in some insects the distal ends of the tubules are closely applied to the hindgut. This condition is known as cryptonephridial condition. Ex : Hymenoptera and Lepidoptera larvae and Neuroptera.

The main function of cryptonephridial condition is to conserve water by with drawing moisture from faeces.

The number of Malpighian tubules varies in insects. The primitive number of Malpighian tubules is six. Malpighian tubules are absent in Collembola and aphids. In Protura, Diplura and Strepsiptera these are represented by papillae.

Malpighian tubules are greatly modified in different ways. Arborescence in *Galleria*, Closely packed diverticula in *Melolontha*, tubules converge and open in to ureter in *Acheta*, the tubules unite in groups and open in common ampulla or bladder in *Dysdercus*.

Malpighian tubules are derived from mesoderm and the transverse section consists of three to eight large and variable shaped epithelial cells with prominent nuclei. Each Malpighian tubules is divided into two regions

- One third proximal region
- Two third distal region

The cells of proximal region bear a brush border while distal part have honey comb border. The outer branches of tubules are richly supplied with fine branches of trachea. The primary function of Malphigian tubules is excretion and regulation of the internal environment by controlling the ions and water balance in the blood and removing the nitrogenous wastes.

The Malphigian tubules come in direct contact with the blood and withdraw water, dissolved salts, amino acids and nitrogenous wastes. These materials pass down the lumen of tubules into the hindgut. Water, salts and nutritive substances are reabsorbed in the proximal part of the tubules or in the hindgut while nitrogenous wastes pass out with faeces. Cryptonephridial tubules serve to conserve water by facilitating its removal from faecal material in the hindgut.

#### **Secondary function of Malphigian tubules**

- Some cells of Malphigian tubules produce sticky substances for a protecting covering of eggs in Chrysomelidae
- The spittle surrounding immature Cercopidae is produced by Malphigian tubules
- Many immature Neuropterans and late larvae of several species of Coleopterans produce silk from specialized cells of Malphigian tubules
- In luminous larvae of *Bolitophila* (Diptera) the light is emitted by thoracic organs formed by the free ends of Malphigian tubules lying beneath the transparent cuticle of thoracic region.

## **2. Integument**

The final products of metabolism are transferred to certain parts of integument. These substances are lost with the exuviae at each moult.

## **3. Wall of alimentary canal**

In Collembola and aphids, (Malphigian tubules are absent) the epithelial cells of midgut are casted off with each moulting and these cells contain excretory material. There is accumulation of crystalline bodies in the walls of hindgut of certain insects. These bodies are salts of calcium and uric acid, which are eliminated directly through the walls of hindgut.

## **4. Labial glands**

In Collembola and Thysanura where the Malphigian tubules are absent, the labial glands are excretory in function. They have an upper sac like part a coiled labyrinth with a gland and excretory duct, which opens at the base of labium. The labial glands take up pigments from the blood and eliminate outside.

**5. Nephrocytes**

Nephrocytes are group of cells found in localized regions of the body. Some nephrocytes are present on the surface of the heart and are called pericardial cells. The nephrocytes take up foreign chemicals of relatively high molecular weight from the hemocoel which can not be taken by the Malphigian tubules.

**6. Fat body**

The fat body is composed of masses of polyhedral cells with vacuolated inclusions. The outer layer is called parietal layer and inner layer is called as visceral layer. Some insects deposit uric acid in special cells of fat body known as Ureate cells. Calcium salts also accumulate in these fat bodies in the form of Calcospherites in the larval Diptera. As the adult emerges from the pupae these are given out as a small drop which is called as meconium.

**7. Oenocytes**

These are large cells found in the body cavity among the tissue of the abdomen and usually associated with the fat cells. These are associated with excretion.

**■ Physiology of excretion**

Uric acid is the main excretory product of the insects and hence the insects are called urecotelic animals. Excretion of uric acid by the terrestrial insects is a physiological activity to reduce the water loss. Uric acid is insoluble in water and it is harmless for any length of time. It crystallizes easily from solution.

Nitrogen metabolites are eliminated by the Malphigian tubules with out the loss of water and essential ions. Uric acid is insoluble in water since it has to pass through the layer of Malphigian tubules it has to be in liquid form. For that the uric acid chemically combines with sodium and potassium carbonates to form sodium and potassium ureates which are water soluble and are readily absorbed by the two thirds of the distal portion of Malphigian tubules from the hemolymph and it is transported through the cytoplasm of the cells. By the time the fluid reaches the proximal part of the Malphigian tubules the uric acid is precipitated by the action of an enzyme, carbonic anhydrase in the alkaline pH prevailing in the proximal region where water and carbonates are pushed into the hemolymph by the action of large number of cilia present in the lumen of Malphigian tubules. In one third proximal portion, uric acid is precipitated in the granular form which finally reaches the hind gut.

Ammonia is the excretory material in aquatic insects. Ammonia is formed by the break down of urea into ammonia and  $\text{CO}_2$  by enzymatic action.

Allantoine is the excretory product in blow fly larvae and *Dysdercus*. In these

insects, the hemolymph is rich in uric acid. The uric acid is broken down by an enzyme, uricase into allantoin which is soluble in water and readily excreted out.

### 3.11 SENSE ORGANS

**The various types of sense organs present in insect are**

- |                          |                       |
|--------------------------|-----------------------|
| 1. Mechanoreceptors      | 2. Chemoreceptors     |
| 3. Auditory organs       | 4. Visual organs      |
| 5. Temperature receptors | 6. Humidity receptors |

#### 1. Mechanoreceptors

Mechanoreceptor is the perception of any mechanical distortion of body, which may result from sense of touch, including contact with solid objects or air or water. The mechanical energy is transformed into electrical energy. This involves deformation of dendrite. This results in the compression of the tubular body which leads to change in permeability of the membrane of the dendrite. Thus receptor potential develops. The magnitude varies with the impact or compression of tubular body. It gets magnified inside and goes to the nervous system and thus the insect is able to perceive the mechanical reception

Various types of mechanoreceptors are

- a. Trichoid sensilla
- b. Campaniform sensilla
- c. Chordotonal organs
- d. Multipolar stretch receptors

##### a. Trichoid sensilla

These are also known as tactile spines or hairs. These are hair like structures projections on the cuticle articulate with body. They are free to move. The hair is produced by the Trichogen cell and socket is produced by the tormogen cell. These hairs are widely distributed over the insect body especially on the antennae, tarsi and cerci. These may also respond to mechanical stress set up in the cuticle and so function as proprioceptors.

##### b. Campaniform sensilla

There are no hairs but a dome is present. These are areas of thick cuticle, oval in shape with long diameter of 20 - 30 microns. They consist of outer homogenous

layer and inner lamellar layer. These occur on all parts of the body subject to stress concentrated at the joints, bases of wings, trochanter etc. The nerves gets stimulated when the dome is raised due to compression. Large number of campaniform sensilla occurs arranged in parallel rows over the base of the halteres of Diptera and are of major importance in flight control

**c. Chordotonal organs (Scoloparia)**

These are usually compound structures composed of a number of specialized sensilla known as scolopophores or scolopidia. Each scolopidia contain a relatively conspicuous sensory body, the scolopale. Each chordotonal organ consists typically of a spindle shaped bundle of scolopophores attached at each end to the integument. A large number of chordotonal organs have been described in the legs of many species, usually in association with the joints between segments. Of wide spread occurrence in the insect leg is the so called subgenal organ which lies in the proximal part of the tibia and consists of an array of chordotonal sensilla suspended between epidermis and a trachea. It responds to vibration of the substrate on which the insect is standing. A highly specialized type of chordotonal organs in the antennae is known as Johnston's organ. It is located in the second antennae segment.

**d. Multipolar stretch Receptors**

Unlike the previously described mechanoreceptors, which contain bipolar neurons and are associated with the cuticle, these consists of a multipolar neuron associated with connective tissue or a muscle.

2. **Chemo - receptors** : Chemo - receptors are highly developed in insects. There are sensory structures stimulated by chemicals. These are perceived by smell even at low concentration hence called olfactory chemoreception. Taste receptors are called gustatory receptors. The chemoreception sensilla is secreted by a equivalents of the trichogen and tormogen cells may also contribute forming part of each sensillum is a group of bipolar neurons. The perikaryon of the neuron is normal, with Golgi bodies, endoplasmic reticulum and numerous mitochondria. The cuticle surrounding olfactory sensilla is pierced by many complex pores through which the chemical stimulus reaches the nerve endings.

**These are of different types**

- a. Sensilla trichoidea
- b. Sensilla basiconia
- c. Sensilla coeloconia
- d. Sensilla placodea

**a. Sensilla trichoidea**

These are hair like structures which may be thin walled or thick walled. They are most abundant and wide spread type of chemoreceptors occurring on various parts of the body. They occur on maxillary palps of grasshoppers where they play a part in food plant selection and on antennae of many species where they have olfactory function. These are also present on the antennae of *Bombyx mori* and also found on the ovipositor of *Musca*. These are gustatory in function.

**b. Sensilla basiconia**

These are peg like or cone like organs distinguished from the trichoid sensilla by the more thick set appearance of the projecting portion. Like the trichoid sensilla they can have a thin or a thick cuticular wall and they respond to various chemical stimuli. Ex : Maxillary palps of Lepidoptera larvae, where they respond to solution of sugars, alcohols, amino acids and other plant constituents.

**c. Sensilla coeloconia**

These are less common and differ from thin walled basiconia sensilla in that the cuticular peg is sunk below the general surface of the cuticle. Hence also called as pig-peg organs. Ex : These are present on the antennae of Coleoptera, Lepidoptera and Diptera.

**d. Sensilla placodea**

This rather distinctive form of sensillum appears as thin, elongate, oval or circular plate of cuticle which is flat or raised into a slight dome. Pores are present over the surface of the plate or around its periphery. Sensilla placodea are best known from the antennae of *Aphis* where they are very numerous and act as olfactory receptors. There are 2 main groups

- i). Olfactory senses (smell)
- ii). Gustatory senses (taste)

**i) Olfactory senses**

The sense of smell in insects is stimulated by low concentration of the vapour phase of great variety of substances which are relatively volatile at ordinary temperatures. The olfactory receptors are trichoid, basiconic, coeloconic, and placoid sensilla, usually if not always provided with many cuticular pores. The excitatory odours induce dendrite polarization of the sense cell (the receptor potential) followed by the nerve impulses in the axon. Inhibitory odours hyper polarize the cell and depress the impulses.

Olfactory receptors are of 2 kinds

- a. Odour specialist cells** : Respond identically to highly specific biologically important

odours like pheromones.

- b. **Odour generalist cells** : Differ in the spectra of their responses to a variety of odours and perhaps provide a peripheral basis for central nervous discrimination of odours.

## ii) Gustatory senses

These are defined by responses to relatively high concentration of non volatile stimulatory substances which come into contact with the receptors in aqueous solution. These are also known as contact chemoreceptors. These mediate important responses in feeding, the rejection of unpalatable substances and in oviposition by adults. The receptors include trichoid, basiconic and styloconic sensilla as well as special forms like the inter pseudo tracheal papilla of Diptera. Contact chemo-receptors are commonly distributed on the tarsi, maxillary and labial palps and less often on the antennae.

## 3. Auditory organs

Receptors used for perceiving the sound are called auditory organs. These are different types

- **Tympanal organs** : These are paired structures always composed of a thin cuticular membrane, the tympanum associated with tracheal air sacs and chordotonal sensilla. In Acridoidea there is tympanal organ on each side of the first abdominal tergum, with an externally visible tympanous surrounded by a cuticular ring. Internally a group of numerous scolopophores form a swelling known as Muller's organ applied to the inner surface of each tympanum and connected by the auditory nerve to the metathoracic ganglion. Two sclerotized process and a pyriform vesicle filled with a clear liquid are intimately associated with Muller's organ. They probably transmit the tympanal vibrations to the sensilla. In Tettigonidae and Grylloidea there is a pair of tympanal organs at the base of each fore tibia. In many families of Lepidoptera conspicuous tympanal organs occur at each side of the metathorax or at the base of the abdomen.
  - a. Auditory hairs
  - b. Johnston's organs

### *Functions*

- They play an important role in mating behaviour of many insects. They help in locating the opposite sex
- They help in aggregation in Acrididae
- In Lepidoptera these are able to perceive the sound coming from bats



#### 4. Visual organs

In insects response to light are mediated by

- |                     |                               |
|---------------------|-------------------------------|
| a. Dermal receptors | b. Compound eyes              |
| c. Dorsal ocelli    | d. Lateral ocelli or stemmata |

Most adult insects and larval hemimetabolous insects have a pair of compound eyes and three single-lens eyes called ocelli

Larval holometabolous insects have one or more single-lens eyes known as stemmata, on either side of the head

##### a. Dermal receptors

Some insects react to light even after the eyes and ocelli have been removed. The general body surface of epidermal cells appear to be sensitive to light

Ex: *Tenebrio* larvae

##### b. Compound eyes

These are made up of a number of similar units called ommatidia. Their number varies with different insects.

These are present in adult pterygote insects and larvae of hemimetabolous insects

These are present separate on the two sides of the head, but in some insects (Anisoptera) contiguous along the dorsal midline. This condition is known as holoptic condition.

##### • Structure of ommatidium

Each ommatidium consists of an optical, light gathering part and a sensory part which transforms light into electrical energy.

In diurnal insects the sensory receptor cells end close to the lens. These are apposition eyes. In nocturnal insects there is clear zone between the lenses and the sensory receptor cells. These are called superposition eyes.

The various parts of ommatidium are

- |                           |                         |
|---------------------------|-------------------------|
| 1. Cornea                 | 2. Corneagen layer      |
| 3. Crystalline cone cells | 4. Ratinula             |
| 5. Primary iris cells     | 6. Secondary iris cells |

- 1. Cornea:** The cuticle covering the eye is transparent and colourless and forms a biconvex corneal lens. The lenses are closely packed together forming an array of hexagonal facets.

2. **Corneagen layer** : Each corneal lens is produced by two epidermal cells, the corneagen cells, which later become with drawn to the sides of the ommatidium and form the primary pigment cells.

3. **Crystalline cone cells** : Below the cornea are four cells called Semper cells. These produce as second lens called the crystalline cone. This is bordered laterally by the primary pigment cells.

4. **Ratinula** : The sensory elements are elongate neurons known as retinula cells. They are eight in number. Each retinula cell extends basally as an axon into the optic lobe. The microvilli of each retinula cell collectively form a rhabdomere. The visual pigment is located within the microvilli.

5. **Primary iris cells** : These are deeply pigmented cells which surround the cells of the crystalline cone and the corneagen layer.

6. **Secondary iris cells** : These are commonly elongated pigmented cells which surround the primary iris cells and the retinula.

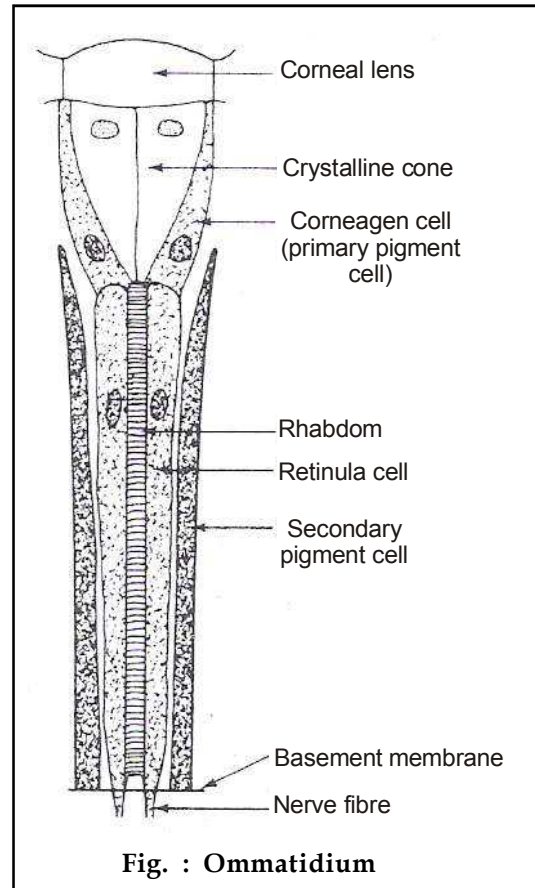


Fig. : Ommatidium

#### • Variation in the lens system

According to the presence and nature of crystalline cone, the types of compound eyes are

- i. **Eucone** : Each ommatidium contains a hard, refractive, conical body secreted within the crystalline cone cells and forming the part of the diaptric apparatus.  
Ex : Odonata, Orthoptera, Lepidoptera, Hymenoptera
- ii. **Pseudocone** : The cone cells are filled with a transparent visous liquid.  
Ex : Brachycera and Cyclorrhapha (Diptera)

**iii. Accone eyes** : The long transparent crystalline cone cells do not secrete any refractive materials.

Ex : Dermaptera, Nematocera, Coleoptera

**iv. Exocone eyes** : The crystalline body is replaced by a cone shaped extension of the inner surface to the cornea, lying distal to the unmodified crystalline cone cells.

Ex : Dermestidae

**c. Dorsal ocelli**

These are present in adult pterygote insects and larvae of hemimetabolous insects. These are three in number forming an inverted triangle. A typical ocellus has a single thickened cuticular lens. Each ocellus contains a large number of retinula cells packed closely together. A rhabdomere is formed on at least one side of each retinula cell and the rhabdomeres of between two and seven cells combine to form rhabdoms. The structure of rhabdoms in the dorsal ocelli is similar to that of compound eyes. Pigment cells are some times present. A reflecting tapetum consisting of ureate crystals may be present at the back of the receptor cells.

**d. Stemmata or lateral ocelli**

These are the only visual organs of larval holometabolous insects. These are also known as lateral ocelli. They occur laterally on the head and vary in number. Stemmata are of two types, those with single rhabdom and those with many rhabdoms. Each stemmata has cuticular lens beneath which is a crystalline lens. Each lens system has seven retinula cells associated with it. Three form a distal rhabdom and four form a proximal rhabdom. A thin cellular envelope lies round the outside of the sense cells and is, in turn shrouded by the extremely enlarged corneagen cells.

## 3.12 INSECT NUTRITION

■ **Insect nutrition**

Nutrition may be defined as the chemicals required by an organism for its growth, tissue maintenance, reproduction and energy to maintain these functions.

Many of these chemicals are ingested by the food, but others are synthesized by the insect itself.

The food ingested and digested by the insect must fulfill its nutritional requirement

for normal growth and development to occur.

A number of carbohydrates, amino acids and vitamins are essential for the development and balance between different constituents is also important.

- **Carbohydrates**

Carbohydrates are important source of energy and may be converted to fats for storage. Carbohydrates are not always required they can be replaced by proteins or fats. The utilization of different carbohydrates depends on the availability to hydrolyze polysaccharides the readiness with which different substances are absorbed and the possession of the enzyme systems capable of introducing true substances into the metabolic processes. There may be differences in the larvae and adult to utilize carbohydrates.

- **Proteins and amino acids**

Amino acids are required for the production of proteins which are used for structural proteins, enzymes and morphogenesis. Although some 20 amino acids are needed in the diet the other can be synthesized from 10 essential amino acids. The ten essential amino acids are phenylalanine, arginine, lysine, leucine, histidine, tryptophan, threonine, isoleucine, methionine and valine. There is some variation in these requirements by different insects. In general the absence of any one of these essential acids prevents growth. The interchangeability of amino acids depends to some extent on the similarity of structure. Tyrosine is synthesized from phenyl alanine.

- **Lipids**

Fatty acids, phospholipids and sterols are components of cell walls and are required by the insects.

Insects can synthesize many fatty acids and phospholipids and can not synthesize sterols

- **Fatty acids**

In insects they are present as diacylglycerides and triacylglycerides. Derivatives of polyunsaturated fatty acids, known as eicosanoids, stimulate oviposition and are important in the reproduction of all insects. They are also required for thermoregulation, lipid mobilization and immune response of caterpillars to bacteria in the haemolymph.

- **Phospholipids (Lipogenic compounds)**

Choline and Myo inositol are constituents of some phospholipids. Some choline is necessary in diet for all insects.

Choline has two main functions in insects

Phosphatidyl cholines (lecithin) which are important in cell membranes

Acetyl choline, essential for neural transmission

Inositol also a component of phospholipids which is essential for phytophagous insects and not for non - phytophagous insects. Some insects synthesize inositol from glucose

- **Sterols**

Insects are unable to synthesize sterols. Hence, they require sterols in diet for normal growth and reproduction. The range of sterols used is limited to those essentially similar to cholesterol with a hydroxyl group at position 3.

Insects feeding on animal tissue obtain cholesterol directly from their food. Majority of the plant feeding insects process the common plant sterols to produce cholesterol. Cholesterol is a necessary precursor in the synthesis of ecdysone.

- **Vitamins**

Vitamins are organic substances which are required in small quantities in the diet since they can not be synthesized. They mostly provide structural components of coenzymes

The water soluble B vitamin, thiamine, riboflavin, nicotinic acid, pyridoxine and pantothenic acid are essential to most insects.

Beta carotene (provitamin A) is required for visual pigments and melanization

Vitamin E (alpha tocopherol) is necessary for fecundity, spermatogenesis and reproduction.

Ascorbic acid is required for cuticular sclerotization. Ascorbic acid is not usually an essential dietary constituents but it is widely distributed in insect tissues indicating that it is synthesized

Biotin is component of the enzyme pyruvate carboxylase.

Folic acid is necessary for nucleic acid biosynthesis.

- **Minerals**

A dietary source of inorganic salts is essential. Their importance lies in the maintenance of an inorganic balance suitable to the activity of living cells.

Iron is central element in cytochromes and must be in diet.

Zinc and manganese play an important role in hardening the cuticle of mandibles in many insects.

Most insects appear to be relatively insensitive to wide range in levels and proportions of the different elements in the diet.

- **Balance of nutrients**

Although some growth occurs with widely differing levels of nutrients, optimal growth requires the levels of different nutrients to be approximately balanced.

The optimal balance of nutrients probably varies continuously in relation to the state of development of the insect.

Insects that feed on other animals have amino acid requirements relative to carbohydrates.

Phytophagous insects require approximately equal amount of amino acids and carbohydrates.

Phloem feeders require high amount of carbohydrates.

***Nutritional effects on the growth and development***

- The quantity of proteins and amino acids ingested are important for optimal growth and development
- The size of the body increases with the nitrogen intake
- Food intake decreases, the duration of development is extended and insect becomes smaller and lighter in weight
- Nutritional poor diets increases the number of larval stages
- Differences in nutrition effects the coloration and morphology
- Different broods of insect develop based on the quality of the food
- In honey bees, the quality of the food given to the larvae by the workers determine whether the larvae will become queen or workers.

■ **Role of microorganisms in insect's nutrition**

Many insects habitually eat food that is nutritionally inadequate. Termites and many beetles feed on wood which is low in proteins and amino acids and contains cellulose and lignin which most insects are unable to digest. Many Homoptera feed on phloem with an imbalance of amino acids others feed on xylem which is deficient in most nutrient chemicals, some Heteroptera, sucking lice (Anoplura) and a few cyclorrhaphous Diptera obtain all their food from vertebrate blood which lacks some of the B vitamins and other minor nutritional components. These insects are able to use these materials through symbiotic associations with micro-organisms. The nutrition of some other insects, feeding on less intractable materials is also enhanced by symbiotic associations. This occurs in cockroaches and crickets which are detritus feeders, in leaf cutting ants, and in some gall forming Cecidomyiidae (fungus gnats). The symbiotic partner is, in some cases an ectosymbiont, but more commonly they are endosymbionts.

- **Ectosymbiotic fungi**

A number of insects have ectosymbiotic relationship with fungi. The insects eat the fungus, but the association differs from that in most fungus eating insects, because the insect manipulates the fungus and so derives nutrients, indirectly, from substrates that would otherwise be difficult for it to utilize.

Ambrosia beetles are associated with fungi that enable them to use xylem of woody plants. The fungi are the principal food of both larvae and adults, and their key role is to concentrate nitrogen, present in very low concentration in wood. They also provide sterols, such as ergosterol which is essential for beetle development.

Bark beetles feed largely on the phloem of woody tissues which is higher in nutrients than the xylem. Fungus genera, *Fusarium* and *Ambrosiella* are associated with ambrosia beetles while *Certocystis* is associated with bark beetles.

Leaf cutting ants (Attini) are dependent on specific fungi for larval food. Workers ants cut leaves, and other parts, from living plants and carry them to the nest. Here, the ants chew the plant fragments, and using feces, they build the chewed fragments into a garden which they inoculate with hyphae from an existing garden. The fungi are Basidiomycetes that only occur in the nests of these ants.

Termites can be separated into seven families: the Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, Serritermitidae, and Termitidae. The first six families are collectively referred to as the “lower termites” and these for cellulose digestion depend on intestinal flagellates. The Termitidae, referred to as the “higher termites” are the largest family and these do not possess symbiotic protozoa in their gut. These ingest a wide range of materials such as leaves, roots, grass, dung and soil. There are two groups within the Termitidae, fungus cultivating and non-fungus cultivating species. Non-fungus cultivating higher termites probably digest their food including cellulose, by enzymes that are produced by their own midgut and salivary glands. Thus intestinal bacteria do not seem to play major role in their cellulose digestion. Cellulolytic bacteria isolated from gut contents reveal the presence of cellulolytic genera belonging to *Cellulomonas* and *Bacillus*.

Termitidae, including the Macrotermitinae, don't have endosymbiotic protozoa, unlike all the other termites. Termites of the fungus cultivating subfamily Macrotermitinae create large fungal gardens in their nests. These gardens are constructed by assembling partially digested plant material that is permeated and further digested by the fungal mycelium. The garden fungi mostly belong to the genus *Termitomyces* and are exclusively found in termite nests. They are maintained and distributed by the termites, which for their part depend on the high nutritional value of the fungi. Termite workers eat the fungus comb, which includes *Termitomyces* mycelium and asexual spores. It breaks down cellulose and lignin and when ingested by the termites, it contributes cellulolytic enzymes to those of the insects. Nitrogen

is also concentrated. In addition to direct nutritional value, the ingested fungi may deliver 'missing enzymes' essential for the completion of cellulose digestion.

Many species of lower termites prefer wood that has been attacked by fungi, which is easier to utilize and richer in protein due to the presence of fungal mycelia.

- **Endosymbionts**

Many insects have microorganisms extra-cellularly in the gut lumen or intra-cellularly in various tissues.

Microorganisms are almost inevitably ingested during feeding and so an intestinal flora is present in most insects. Insect with straight alimentary canals contain fewer micro organisms than those with complicated guts. The type of micro-organisms present in the gut is largely depending on the environment in which the insect lives. Adult tephritid flies have a dorsal diverticulum of the esophagus in which bacteria accumulate.

Microorganisms in the gut contribute to the insect's nutrition.

Detritus feeding cockroaches and crickets have bacteria in the hind gut. They increase the ability to digest plant polysaccharides and oligosaccharides.

Scarab beetle larvae which feed in decaying wood have bacterial flora in hindgut which helps in digestion of the food.

Some termites and wood eating cockroaches have flagellates in the hind gut which are important in the digestion of wood. These insects have symbiotic relationship with hindgut fauna and these are transferred from generation to generation.

**Insects feeding on nutritionally poor diets and their associated symbiotic organisms**

| Type of food | Insect order / family           | Microorganisms       |             | Contribution to insect |
|--------------|---------------------------------|----------------------|-------------|------------------------|
|              |                                 | Position in the body | Type        |                        |
| Wood         | <i>Cryptocercus</i> (Blattodea) | Hindgut              | Flagellates | Cellulose digestion    |
|              | Kalotermitidae (Isoptera)       | Hindgut              | Flagellates | Cellulose digestion    |
|              |                                 | Hindgut              | Bacteria    | Nitrogen fixation      |



|                 |                            |                         |          |                                                   |
|-----------------|----------------------------|-------------------------|----------|---------------------------------------------------|
|                 | Macrotermitinae (Isoptera) | Ectosymbionts           | Fungi    | Cellulose digestion and concentration of nitrogen |
|                 | Anobiidae (Coleoptera)     | Midgut cecal epithelium | Yeasts   | Essential amino acid                              |
|                 | Scolytinae (Coleoptera)    | Ectosymbionts           | Fungus   | Concentration of nitrogen                         |
|                 | Platypodidae (Coleoptera)  | Ectosymbionts           | Fungus   | Concentration of nitrogen and sterols             |
|                 |                            | Hindgut                 | Bacteria | Nitrogen fixation                                 |
|                 | Siricidae (Hymenoptera)    | Ectosymbionts           | Fungus   | Cellulose digestion                               |
| Green plants    | Attini (Hymenoptera)       | Ectosymbionts           | Fungus   | Cellulose digestion                               |
| Phloem          | Aphididae (Homoptera)      | Hemocoel                | Bacteria | Amino acids                                       |
|                 | Delphacidae (Homoptera)    | Hemocoel                | Bacteria | Amino acids, Sterols                              |
| Vertebrate food | Anoplura                   | Variable                | Bacteria | B vitamins                                        |
|                 | Cimicidae                  | Hemocoel                | Bacteria | B vitamins                                        |
|                 | Glossinidae                | Midgut epithelium       | Bacteria | B vitamins                                        |
| Detritus        | Blattodea                  | Hindgut                 | Bacteria | Carbohydrate digestion                            |
|                 |                            | Fat body                | Bacteria | Nitrogen recycling                                |

- Intracellular microorganisms**

Intra - cellular microorganisms fall into two groups, those that occur in normal cells of an insect, and those that are restricted to special cells with discrete morphology known as mycetocytes. The former have been reported from many insect orders

and they have no effect on the biology of the host insect. Mycetocyte microorganisms are universal amongst species that feed on vertebrate blood through their lives such as Cimicidae, Anoplura, Glossinidae and Hippoboscidae but they are not found fleas, mosquitoes and horse flies that have larvae which are not blood sucking. They are almost present in Homoptera the only exception being those feeding on tissues other than phloem or xylem. All the wood feeding beetles and insects feeding on feathers and skin debris of birds have mycetocyte micro-organisms.

- **Types of microorganisms**

Non - pathogenic microorganisms, known as mycetocyte symbionts, are located in specialized 'mycetocyte' cells of many insects that feed on nutritionally unbalanced or poor diets. The insects include cockroaches, Cimicidae and Lygaeidae (Heteroptera), Homoptera, Anoplura, Diptera, some formicine ants and many beetles.

The mycetocyte microorganisms of aphids, weevils and many other insects are bacteria. Yeasts are present in Anobiidae and Cerambycidae. In Fulgoridae both yeast and bacteria are present. Mycetocytes are large polyploid cells. These are scattered amongst the principal cells in midgut epithelium in Anoplura, while, in cockroaches they are scattered through the fat body. In other insects they are aggregated to form organs known as mycetomes often in the hemocoel.

- **Role of mycetocyte symbionts in insect's nutrition**

1. The symbionts play a key role in nitrogen management, synthesize a range of essential amino acids and in aphids and beetles they upgrade non essential amino acids to essential amino acids. In aphids, sterols are supplied by symbionts. Yeasts associated with some aphids, plant hoppers and beetles produce sterols.
2. Most mycetocyte symbionts are prokaryotes. None has been cultured *in vitro* and their taxonomic position is obscure. Yeasts have been reported in Cerambycidae and Anobiidae (Coleoptera) and a few plant hoppers. They are culturable and those in anobiids have been assigned to the genus *Torulopsis*.
3. The mycetocyte cells may be associated with the gut, lie free in the abdominal haemocoel or be embedded in the fat body of the insect. The mycetocytes are large polyploid cells which rarely divide and the symbionts are restricted to their cytoplasm.
4. The mycetocyte symbionts are transmitted maternally from one insect generation to the next. In many beetles (Anobiidae, Cerambycidae, Chrysomelidae and Curculionidae), the microorganisms are smeared onto the eggs and consumed by the hatching larvae. In other insects, they are transferred from mycetocytes to oocytes in the ovary, a process known as transovarial transmission.

5. Within an individual insect, the biomass of symbionts varies in a regular fashion with age, weight and sex of the insect. Suppression of symbiont growth rate and lysis of 'excess' microorganisms may contribute to the regulation of symbiont biomass.
6. The mycetocyte symbionts have been proposed to synthesize various nutrients required by the insect. The symbionts of beetles and haematophagous insects may provide B vitamins and those in cockroaches and Homoptera essential amino acids. The role of symbionts in the sterol nutrition of insects is equivocal.
7. Mycetocyte symbionts may have evolved from gut symbionts or guest microorganisms. The association is monophyletic in cockroaches but polyphyletic in many groups, including the sucking lice, beetles and scale insects.
8. The mycetocyte symbioses are commonly regarded as mutually beneficial but the selective advantage to the microbial partner is unclear.

### 3.13 ARTIFICIAL DIETS

#### ***Definition***

The term artificial diet, when applied to insects is one that has been defined as any diet that is not the natural food of the insect. It includes all the various terms such as synthetic, chemically defined, holidic, meridic, and oligidic.

A nutritionally complete diet for most insects in axenic culture must contain all or most of the proteins or amino acids including ten essential ones, carbohydrates, fatty acids, cholesterol, choline, inositol, pantothenic acid, nicotinamide, thiamin, riboflavin, folic acid, pyridoxine, biotin, vitamin B<sub>12</sub>, beta carotene or vitamin A, alpha tocopherol ascorbic acid, several minerals and water.

#### ***Uses of artificial diets***

- Diets are used for studying insect nutrition
- Used for studying biochemistry, behaviour and other biological process
- Testing of compound for physiological effects
- Maintaining colonies
- Mass production of insects for various purposes

#### **Insect artificial diets are classified into 3 types**

1. Holidic diet
2. Meridic diet
3. Oligic diet

**1. Holidic diet**

Diets in which the ingredients can be represented by chemical formulae are known as chemically defined diets or holidic diets.

These diets are used primarily for nutritional studies. Most nutritional studies have been conducted with diets containing one or more of the following ingredients such as agar, protein (casein) vegetable oil, starch, and cellulose. With appropriate descriptions, these diets could be designated as defined diets.

**2. Meridic diet**

Diets which contain one or more unrefined substances from plant, animals or micro organisms such as plant tissue, liver extract, and yeast products.

The main characteristic of these diets is that most of the nutrients are provided as pure or refined substances also. The large number of diets for the laboratory rearing of insects is included in this group.

**3. Oligic diet**

These diets are made up of crude material. They are designed to imitate the natural food and are assumed to have all the required nutrients with undigestible inert material. These diets are economical and are used of mass rearing of insects.

### **3.14 Insect flight and fuels**

The flight of an insect involves very rapid oxidation of respiratory fuels by the flight muscles. Flight is the most energy demanding activity undertaken by insects and its maintenance is dependent upon adequate and continuous supplies of fuels and oxygen to the flight muscles. Oxygen is supplied plentifully, directly to the cells by the highly developed tracheolar system which ensures fully aerobic respiration at even the highest wing beat frequencies. Insect circulatory system create problems in the rapid exchange of fuels, metabolites, and hormones between the tissues and the hemolymph. Insects appear to have successfully avoided this potential handicap by carrying high concentrations of fuels in the hemolymph to ensure steep concentration gradients between the hemolymph and tissues. Carbohydrate and lipid concentrations are typically up to 80 times those found in vertebrate blood. Insects transport their major fuels predominantly in forms that are non-reducing, neutral, and contribute less to osmotic pressure. Hence, fats are transported usually as neutral lipids which form part of lipoproteins, and carbohydrates are transported as trehalose, a disaccharide of glucose. Other insects have adopted amino acids as the major fuel for flight' and these, although again present in most insects at high concentrations compared with vertebrate systems, do not appear to have deleterious effects.

*Apis mellifera* only fuels flight with carbohydrates. Insects that perform long-term flights such as migratory locust (*Locusta migratoria*), use carbohydrates during the initial phase of flight and lipids to sustain activity. Some blood-feeding insects use the amino acid proline as their main fuel.

The nature and storage of fuels for flight

- i. **Carbohydrates :** Carbohydrates are used by many insects as the sole fuel for flight and are used by others at the start of flight or for short term flights. Utilization of carbohydrates confers some advantages, because small quantities of glycogen are stored in the flight muscles themselves and are therefore immediately available, and the transport forms (trehalose together with small amounts of glucose) are readily soluble, and presumably, easily taken up by the tissue. The major disadvantage of these fuels is that the storage form, glycogen, is very bulky; for every 1 g of glycogen stored, 2 g of water is also necessary to maintain its hydration. It seems therefore not feasible to store the large amounts of glycogen which would be required to sustain prolonged flight. Glycogen is nevertheless stored in small amounts in the fat body, flight muscles, and the gut. In many insects however, the major pool of carbohydrate is trehalose in the hemolymph, which in locusts exceeds that in the fat body and gut wall about tenfold. However, carbohydrate stores in insects appear to provide sufficient energy for a maximum of only about 30 to 45 min of continuous flight, although food in the crop may substantially increase the duration of flight. In addition it is likely that some insect tissues (e.g., the nervous system) have an obligatory requirement for carbohydrate and the hemolymph concentrations of trehalose may be prevented from falling below certain levels. During long term flight in locusts and *Manduca*, hemolymph trehalose is maintained at about 50 and 40% of preflight levels, respectively. For insects which fly for relatively short periods, e.g., bees and flies, storage of fuels in the tissues is probably less important because frequent stops for food may be possible; flight exhausted *Drosophila* can return to flight within 30 sec of feeding on a sugar solution and in flies and other insects, the crop and midgut contents may be important sources of readily accessible carbohydrate. However, in those insects which do not feed as adults (e.g., some moths and butterflies), or which undertake long uninterrupted flights of several hours typically during migration, it is not possible to store economically large amount of energy required in the form of carbohydrates, such insects store energy predominantly as fats.
- ii. **Lipids:** In migrating lepidopteran and orthopteran insects, lipid is the preferred fuel for sustained flight activity. Lipids are stored primarily as triacylglycerols in the fat body. However, in some species, e.g., in *Lethocerus* sp. and *Aphis fabae*, lipids are stored also in the flight muscles, and in *Rhodinus prolixus* and *Triatoma infestans*, abundant lipid droplets are found in close association with the mitochondria of the flight muscles. This presumably reduces transport distances and possible delays in

their mobilization and transport from the fat body.

The major form in which lipids are transported through the hemolymph is as diacylglycerols, although many lipid-utilizing insects may also use carbohydrates to some extent during flight. Locusts, for example, use carbohydrates rapidly during the initial stages of long-term flight while they mobilize lipids from the fat body. In adult *Manduca sexta*, which have high levels of lipids even at rest, carbohydrates are also used rapidly during the first 5 min of flight. Adipokinetic hormone (AKH) is a short peptide lipid mobilising hormone and is responsible for regulating fuel transport in the haemolymph. At the flight muscles, the diacylglycerols are hydrolyzed to free fatty acids (which are taken into the flight muscles to provide the energy for flight) and glycerol. Although glycerol is used as a fuel for flight to a small extent, and flight muscles will oxidize this substrate in vitro in *Schistocerca* and *Locusta* most of the glycerol liberated by the flight muscles is released into the hemolymph where concentrations rise up to six to ten fold during long-term flight when diacylglycerol becomes the major fuel. Glycerol is taken up by the fat body where it can be converted to trehalose or esterified to form diacylglycerols.

In most lipid-utilizing insects, adequate supplies of lipids to the flight muscles during flight are provided by the mobilization of triacylglycerol stores in the fat body. In locusts this leads to a gradual increase in the concentration of hemolymph diacylglycerols from low levels (4 to 5  $\mu\text{g } \mu\text{l}^{-1}$ ) at rest to about 20  $\mu\text{g } \mu\text{l}^{-1}$  after an hour of flight. The water-insoluble nature of neutral lipids dictates that they are transported through the hemolymph as part of soluble complexes, lipoproteins, to enable high concentrations to be attained.

- iii. Amino acids: Amino acids are generally present in the hemolymph and tissues in high concentrations, and in many insects, these may contribute to the overall supply of energy to the flight muscles. However, in species such as *Glossina morsitans*, *Leptinotarsa decemlineata*, and *Melolontha melolontha*, the amino acid proline is the primary source of energy for flight. In both *Glossina* and *Leptinotarsa*, flight leads to a prolonged decrease in the concentration of proline in the hemolymph, but the alanine concentration increases. After cessation of flight, resting levels of these metabolites are rapidly restored. The major renewable source of proline in both these insects appears to be triacylglycerol from the fat body. Such a strategy has certain advantages over the mobilization of diacylglycerols because proline is water soluble and the need to maintain metabolically expensive lipoprotein carrier mechanisms is avoided.



# Ecology

  
UNIT

4

## 4.1 CONCEPT OF ECOLOGY

### ■ Ecology

Ecology (Greek word, oeko means “house” or “living relations”; logy “study of”) is the scientific study of the distributions, abundance and relations of organisms and their interactions with the environment.

Ecology includes the study of plant and animal populations, communities and ecosystems. Ecosystems describe the web or network of relations among organisms at different scales of organization.

Study of ecology includes

- Life processes explaining adaptations
- Distribution and abundance of organisms
- The movement of materials and energy through living communities
- The successional development of ecosystems, and
- The abundance and distribution of biodiversity in context of the environment

### ■ Ecosystem

#### The concept of the ecosystem

- Tansley coined the term ‘ecosystem’ to emphasize that organisms cannot be separated from their environment, with which they form one physical system
- The ecosystems are of various kinds and can exist at several scales
- Ecosystem as a self-regulating entity, maintaining specific internal conditions despite fluctuations in external environments
- In an ecosystem energy is derived from the sun is transferred by means of chemical processes through soil and vegetation up the food chain, and then by decomposition through the cycle again

### **Characteristics of an ecosystem**

Smith (1966) has emphasized the following general characteristics of most ecosystems

- i. The ecosystem is major structural and functional unit of ecology
- ii. The structure of an ecosystem is related to its species diversity. An ecosystem harbours more than one population and all these populations within the ecosystem form a community
- iii. The function of the ecosystem is related to the energy flow and material cycling through and within the system
- iv. The relative amount of energy needed to maintain an ecosystem depends on its structure. The more complex the structure, the lesser the energy it needs to maintain itself
- v. Ecosystem matures by passing from less complex to more complex states
- vi. Both the environment and the energy fixation in any given ecosystem are limited and cannot be exceeded without causing serious undesirable effects
- vii. Alterations in the environment represent selective pressure upon the population to which it must adjust. Organisms which are unable to adjust to the changed environment are eliminated

## **4.2 BIOTIC AND ABIOTIC FACTORS**

Howard and Fiske divided environmental factors into two

1. Catastrophic factors : Which are independent of the initial population

Ex : Climatic factors

2. Facultative factors : Which are dependent of the initial population

Ex : Food, predators and parasites

Smith used the terms density dependent and density independent factors as synonyms of facultative and catastrophic factors respectively. Accordingly the density dependent factors are mostly biotic and density independent factors are principally abiotic factors.

The different abiotic factors are

- I. Temperature
- II. Moisture / humidity
- III. Light
- IV. Wind and air currents



V. Water currents

VI. Edaphic factors

## I. Temperature

Of all the physical factors of environment, temperature is the most important.

Temperature acts on insects in two fold manner

1. By acting directly on survival and development
2. Indirectly through food, humidity, rainfall, wind atmospheric pressure etc.,

All insects are poikilothermic i.e. their body temperatures follow more or less closely that of surrounding medium. The narrow band of temperature where physiological activities of the insect takes place is called preferred temperature or the temperature preferendum (generally 15 - 35 °C).

Exposure to temperatures beyond the favourable range whether low or high may result in death of the insect or may retard its growth and development.

The temperature adaptation is referred to acclimation while the response of organism to it referred to as acclimatization.

### Different effects of temperature are

- i. Indirect effects of temperature
- ii. Lethal influence of high temperature
- iii. Effect of fluctuating temperature
- iv. Temperature and development
- v. Temperature and fecundity
- vi. Temperature and dispersal

#### i. Indirect effects of temperature

Temperature may also effect survival by influencing the rate utilization of food reserves.

The lowest temperature at which organisms can live indefinitely is the minimum effective temperature. The lowest temperature which permits survival is the minimum survival temperature. For the same species occupying two different habitats these temperatures are different due to variation in their acclimation temperatures.

**Cold hardiness** : The ability of insect to withstand the lower temperatures. Some insects are able to avoid freezing because they can tolerate super cooling i.e. being cooled below the point of freezing but with out freezing actually taking place. This is due to the cryoprotective compounds such as glycerol, sorbitol and erythritol. These

are found in the tissues of over wintering insects to prevent tissue destruction as well as depressing the hemolymph freezing point.

#### ii. Lethal influence of high temperature

The temperature at which death occurs is called fatal high temperature. The death of insect is due to desiccation and increased rate of metabolism with consequent wastage of energy.

#### iii. Effect of fluctuating temperature

Fluctuating temperature affect the insect in the following ways

- Fluctuating temperature makes the insect to undergo diapause.
- Different stages of insects significantly respond to fluctuating temperature.
- The effect of fluctuating temperature is accelerating only when one temperature is below the threshold of development but not too low to be injurious.

#### iv. Temperature and development

Insects complete their development more rapidly in warm weather than in cool. According to Vant Hoff's law when temperature is increased by 10°C the rate of development is doubled.

**Thermal constant:** The total heat energy required to complete a certain stage of development in the life cycle of a species or in the completion of physiological process is constant and called as thermal constant

**Day degree:** One degree of mean temperature lasting for one day

**Developmental unit:** The amount of development produced in given unit time by the increase of one degree centigrade

$$U = T / nt$$

where U is developmental unit; T is Total development

nt is Thermal constant

#### v. Temperature and fecundity

Fecundity is maximum towards moderately high temperature and declines as the upper and lower limit is reached. The fecundity may be influenced by environmental factors other than temperature, such as food, moisture, population and age of species.

#### vi. Temperature and dispersal

In nature dispersal of insect population does take place particularly when predators are abundant or food is sparsely distributed in its habitat. Temperature may effect the dispersal rate.

**II. Moisture / humidity**

A constant supply of moisture is needed for metabolic reaction as well as for the dissolution and transport of salts. The water content in insects varies from less than 50 % to more than 90 % of the total body weight. Soft bodied insects such as caterpillars tend to have comparatively large amount of water in their tissues, where as many insects with hard bodies tend to have some what lesser amounts. Active stages commonly have higher water content than dormant stages.

**Moisture preferendum**

Insects have a tendency to congregate with in a narrow range of humidity and that range is the preferred humidity or moisture preferendum.

Activities of insects tend to become maximum at a specific range of humidity *i.e.* the optimum range. This optimum range varies from species to species and even between different development stages of the same insect species.

**Different effects of moisture are**

- i) Effect of moisture on development and fecundity
- ii) Effect of moisture on insect coloration
- iii) Moisture balancing and conserving devices in insects
- iv) Effect of extremes of moisture conditions
- v) Humidity and survival
- vi) Interaction of temperature and humidity

**i) Effect of moisture on development and fecundity**

The rate of oviposition in insects increases greatly with increasing humidities. But in *Sitophilus oryzae* fecundity increases steadily up to 70% RH but there is no decline in number of eggs laid if the humidity is increased to 90%.

**ii) Effect of moisture on insect coloration**

Insect colouration is influenced by moisture content of the environment in some insects. In cooler areas dark colour helps to absorb sun light which raises the body temperature and helps insects in getting rid of excessive moisture in the body. In desert insects light colour apparently helps to reflect the sun rays and thus saves the insect from excessive evaporation.

**iii) Moisture balancing and conserving devices in insects**

When the percentage of moisture content in the body of an insect is equal to the RH of the atmosphere, the insect is described as being in a state of moisture equilibrium. To maintain water content with in well defined limits, insects acquire

water by drinking or by absorption from moist surface or air.

The various structural devices for water conservation include: the waxy layer of the epicuticle that prevents water loss through the integument, spiracular closing mechanism that regulate moisture loss from the tracheal system and excretory organs that retain water from urine and faeces.

#### iv) Effect of extremes of moisture conditions

There is an optimal range of moisture in which a given species thrives. Mortality may occur under condition of excessively low environmental moisture content. The lethal influence of exceptionally low moisture condition on insects depend on the rate at which water loss is regulated by ambient temperature wind velocity or body movements. In order to escape this exceedingly low moisture condition, insects may under go diapause or aestivation.

#### v) Humidity and survival

Survival is indirectly affected by extremely high humidity condition that favour the spread of viral, fungal and bacterial diseases. If excessive moisture does not kill an insect, it may seriously affect the length of its life cycle.

Extremes of environmental moisture content directly influence many of the activities of insects including feeding, development and reproduction.

High humidities are more favourable for embryonic stages than low humidities.

#### vi) Interaction of temperature and humidity

Temperature exerts a relatively greater effect on insects at the extremes of moisture condition and vice versa. High humidity proves fatal more readily than lower humidity at ordinary temperature. Most insects are capable of resisting high temperatures under high relative humidity. For each insect there are certain limits of temperature and humidity with in which they can live.

### III. Light

Light is essential ecological factor for many biological processes such as orientation or rhythmic behaviour of insects, bioluminescence, periodicities of occurrence and periods of inactivity. Unlike temperature light is non lethal factor. A characteristic feature of light is its quantitative shift from a minimum to a maximum and vice versa in a short time.

Influences of light on different movement of insects are

- i) Phototaxis
- ii) Phototropism

- iii) Photo periodism
- iv) Effect of alternating light and darkness on insects
- v) Bioluminescence or phosphorescence

i) **Phototaxis** : Oriented locomotory movements towards and away from a source of light is referred to as phototaxis. It may be + ve or – ve.

ii) **Phototropism** : Occurs in sessile insects involves light directed growth mechanisms.

iii) **Photo periodism** : The response of insects to environmental rhythms of light and darkness is termed as photo periodism. Each daily cycle inclusive of a period of illumination followed by a period of darkness is called the photoperiod. The term photophase and scotophase are also used to denote the period of illumination and the period of darkness respectively. The photo tactic reaction of insects to light can be modified or reversed by several factors such as temperature, moisture, food and age.

**iv) Effect of alternating light and darkness on insects**

Some are active during the day (diurnal), some are active during night (nocturnal). Some at dawn (matinal) and still others at dusk (crepuscular). Initiation of diapause is by day length of shorter duration. Photoperiod in addition determines whether it is embryonic diapause (*Bombyx mori*). Larval diapause (*Euproctis*), pre pupal diapause (*Plodia interpunctella*), pupal diapause (*Pieris brassicae*) or imaginal diapause (*Culex* and *Anopheles*).

Many insects exhibit continuous growth under long day condition (long day forms) or become arrested in growth under going diapause (short day forms). Long day forms have the capacity to produce several generations during the growing seasons unlike as in short day forms, where there may be 2 generations in a year.

Feeding, mating, oviposition as well as emergence rhythms in insects are influences by photoperiod. In *Aedes aegyptii* active periods of feeding appear to be during the morning or just before the sunset.

**v) Bioluminescence or phosphorescence**

Employment of luminescence in recognize of one sex by another. Ex: Fire flies.

#### **IV. Wind and air currents**

Two basic types of air currents

- a. Horizontal moving convention current
- b. Vertical moving convention current

Most insects will not take flight when the speed of wind exceeds the normal flight

speed. Strong flying insects tend to fly with the winds during migrations and are displaced along distance as in case of spruce budworm moths. Air movements may be directly responsible for the death of insects, first severe wind coupled with heavy rains may cause mortality.

## V. Water currents

Water currents often determine which species will live in an area. The various genera of mayflies may be classified into still or rapid water forms.

Caddis fly and mayfly larvae may be found under condition of relatively high oxygen concentration, midge and black fly larvae at some what lower concentration while certain mosquito at a very low concentration.

## VI. Edaphic factors

Edaphic factors include the structure, texture and composition of soil along with its physical and chemical characteristics.

Some organisms help in maintenance of soil fertility through nitrogen fixation. Some organisms like earth worms, millipedes etc, help in humus formation.

The loams soils are most preferred by insects. Well aerated soil is a prerequisite of all soil insects (White grub). Drainage and texture together exert considerable influence in the distribution of insects which pass part of their life in soil.

Nitrogen deficiency lowers the productivity of some species of insects but results in out - break of others. Height of mountain chains and steepness of the slope also effect the climate of an area, thus influencing the distribution of certain insects. The mountain range and large bodies of water such as seas act as physical barriers to the spread of insects.

## BIOTIC FACTORS

Under natural conditions organisms live together influencing each others life directly or indirectly for growth, nutrition and reproduction.

It is of two types

**Intra - specific** : Between the same species.

**Inter - specific** : Competition between different species.

Quality and quantity of food play an important role in the survival, longevity, distribution, reproduction, speed of development etc.,

Biotic factors deal with

I. Relationship among organisms

II. Interrelations with plants

III. Food in relation to insects

**I. Relationship among organism**

A) Intra - specific interactions

B) Inter - specific interactions

**A) Intra specific interactions**

The intra specific interactions are governed by

- a. Aggregation of individuals of the same species
- b. Concurrence
- c. Cannibalism
- d. Association of sexes
- e. Parental care
- f. Social life

**a. Aggregation**

Aggregation refers to the tendency of some insects to concentrate in numbers larger than found in normal distribution. In certain cases insects may become gregarious by coincidence. These modify the environment i.e. micro climate, their by bringing about the changes in the morphology, physiology and ethology of aggregating members.

**b. Concurrence**

Very large numbers of insects crowd together in mass assemblage at one time for hibernating, feeding or pairing (aphids). Concurrence is disadvantageous to the species because it results in reduction of food and contamination of surroundings etc.

**c. Cannibalism**

The intra - specific competition takes place between members of the same species and are inversely accentuated by crowding (*Helicoverpa armigera*).

**d. Association of the sexes**

The sex ratio in insects plays an important part in the build up of their population at the same temperature (House fly).

**e. Parental care**

It includes care of egg and brood nests provision of larval food either on the plant itself, or providing food material from outside (Earwigs).

**f. Social life**

Some insects live in colonies that have a division of labour among individuals and an interchange and sharing of food and other things among members of the colony (Ants and termites).

**B) Inter specific Interactions**

These are 3 types

- a) Symbiosis : One or both are benefited
- b) Antagonism : At least one should be harmed
- c) Neutrality : Neither harmed or benefited

**1. Symbiotic relations are 2 ways**

- i) Positive
- ii) Negative

**i) Positive interactions include**

- a. Commensalism
- b. Cooperation
- c. Mutualism

**a. Commensalism :** It is an unbalanced relationship in which one partner is benefited, the other remaining un benefited and unharmed. One partner is host and other is guest.

Ex : Staphylinid beetle inhabit nests of social Hymenoptera as commensal and utilize their stored food

Commensalism in which the association between, two organisms is for the purpose of transport is termed phoresy or hitch hiking.

Ex : Mallophaga

**b. Cooperation :** Cooperation is found in bee colonies where there is division of labour among individuals of a colony.

**c. Mutualism**

Insect – insect mutualism: Ants feed on honey dew secreted by aphids

Insect – plant mutualism : Insect that feed on pollen and nectar have a mutualistic relationship to their plant hosts

Allotrophous : They visit the flower but do not play in pollination Ex : Thrips

Hemitrophous : Some extent of pollination. Ex : Bombycidae, Syrphidae

Eutrophous : Maximum pollination. Ex : Bees

**ii). Negative interactions**

**a. Competition :** Individuals of same species or different species compete for space,



light, food etc.

Competition exclusion principal : Gause principal: No two species occupy the same ecological niche

Ex : *Tribolium castaneum* and *Tribolium confusum*, below 29 °C, *T. confusum* will survive

- b. Perfect competition** : In perfect competition there is elimination of species. Same species and elimination is very fast is called hyper perfect competition.
- c. Imperfect competition** : It is competition between different species and there is no elimination.
- d. Parasitism** : All inter specific interactions where by species benefit at the expense of another. Host of hyper parasites is called primary parasitoids. Hyper parasitoids may be secondary, tertiary or even quaternary parasitoids.

### Comparison of parasite, parasitoid and predator

| S.No. | Character           | Parasite   | Parasitoid                 | Predator |
|-------|---------------------|------------|----------------------------|----------|
| 1     | Terminology of food | Host       | Host                       | Prey     |
| 2     | Free living         | Sometimes  | Larvae - No<br>Adult - Yes | Yes      |
| 3     | Host range          | Narrow     | Variable                   | Broad    |
| 4     | No. of individuals  | One        | One                        | Many     |
| 5     | Effect on host      | Not killed | Killed                     | Killed   |
| 6     | Fecundity           | High       | Variable                   | Low      |
| 7     | Size                | Small      | Similar or smaller         | Larger   |
| 8     | Carnivorous example | Body louse | Ichneumon wasp             | Mantid   |
| 9     | Herbivorous example | Aphid      | Bean weevil                | Cutworm  |

### e. Predatism

A predator kills but never eliminates the prey completely. An obligate predator feeds only on one species of prey. A facultative predator feeds on more than one species.

## II. Insect plant relationship

Plant is less damaged due to heritable characteristic called resistance. According to R.H.Painter, resistance is of 3 types

- a. Non - preference for oviposition, shelter or food
- b. Antibiosis
- c. Tolerant

Hairy varieties are resistant to leaf hoppers. Secondary plant substances may have toxic, repellent, deterrent or hormonal effect on insects. Substances with moulting hormone activity have been found in several ferns (Gymnosperms). These substances protect plants by interfering with insect development. Juvenile hormones are also found in plants like Balsam fir and eastern hemlock.

## III. Food in relation to insects

Quantity and quality of food play an important role in its survival, longevity, distribution reproduction and speed of development.

### a) Quantity of food

Absolute shortage : Food being completely destroyed.

Effective food shortage : Food shortage may occur in patches through the distribution of a given insect populations.

**The causes of absolute and effective food shortages are**

- Large number of the same individuals per unit quantity of food (intra - specific competition)
- More than one species consuming the same food material (inter - specific competition)
- Species that influence the food of their species with out consuming it
- Other environmental factors

### b) Quality of food

Egg production, larval development, longevity and size of insects may be greatly influence by the quality of available food. The queen of social Hymenoptera and termites lay eggs through out their life and hence require food constantly. The quality of ingested food in some insects influences the out come of development. The differences between workers and queen honey bees depend entirely on the diet that each receives during larval development. After 3<sup>rd</sup> day of larval development larvae destined to become workers receive a diet containing increasing amount of honey, where as queen larvae continue to be fed on royal jelly.

Changes in the quality of food like wise induce the appearance of winged forms and migratory behaviour in aphids.

### 4.3 POPULATION DYNAMICS AND THEORIES

**Population ecology** is a major sub - field of ecology that deals with the dynamics of species populations and how these populations interact with the environment.

**Population dynamics** is the branch of life sciences that studies, short- and long-term changes in the size and age composition of populations, and the biological and environmental processes influencing those changes.

Population dynamics deals with the way populations are affected by birth and death rates, and by immigration and emigration, and ageing populations or population decline.

Population is affected by 3 dynamic rate functions. They are

1. Natality or birth rate, often recruitment, which means reaching a certain size or reproductive stage.
2. Population growth rate, which measures the growth of individuals in size and length.
3. Mortality, which includes harvest mortality and natural mortality.

If  $N_1$  is the number of individuals at time 1 then

$$N_1 = N_0 + B - D + I - E$$

where  $N_0$  is the number of individuals at time 0, B is the number of individuals born, D the number that died, I the number that immigrated, and E the number that emigrated between time 0 and time 1.

#### ➤ Intrinsic rate of increase

The rate at which a population increases in size if there are no density-dependent forces regulating the population is known as the *intrinsic rate of increase*.

$$(dN / dt)(1 / N) = r$$

Where  $(dN/dt)$  is the rate of increase of the population

N is the population size

r is the intrinsic rate of increase

An important concept in population ecology is the  $r/K$  selection theory.

$r$  is the intrinsic rate of natural increase in population size, density independent

$K$  is the carrying capacity of a population, density dependent

An  $r$ -selected species (aphids) is one that has high rates of fecundity, low levels

of parental investment in the young, and high rates of mortality before individuals reach maturity. Evolution favours productivity in *r*-selected species.

*K*-selected species (such as humans) has low rates of fecundity, high levels of parental investment in the young, and low rates of mortality as individuals mature. Evolution in *K*-selected species favours efficiency in the conversion of more resources into fewer offsprings.

### ■ Population theories

The various theories of population ecology are

1. Nicholson's theory
2. Theory of Andrewartha and Birch
3. Milne's theory
4. Chitty's theory
5. Pimental's theory
6. DeBach's theory

1. **Nicholson's theory** : Population dynamics are self governing systems. They regulate densities in relation to their own properties and those of their environments. According to Nicholson the factors which regulate the population are

Density legislative factors : These are the factors whose effect upon population density is not altered by change in number of a population.

Density governing factors : These respond to change in population growth when numbers increase and relaxing their opposition on population when number decrease.

These factors were substituted by density independent and density dependent factors.

2. **Theory of Andrewartha and Birch** : Density dependent factors do not exist and that populations are groups of individuals, each having a different environment and that balance in a population is achieved by the favorability or unfavorability of the environment in time. According to this theory the number of animals in natural population may be limited in 3 ways

By shortage of material resources, (food, habitat etc.)

By inaccessibility of these material resources relative to the animals capacity for dispersed and searching

By shortage of time when the rate of increase is positive

3. **Milne's theory** : According to this theory there are 3 factors which are responsible for population regulation

Density independent factors (weather, parasites etc.)

Imperfectly density dependent factors (Intra specific)

Perfectly density dependent factors (Inter specific, competition for food and space)

A rise in population results from good weather leads to emigration. As a consequence of intraspecific competition population levels will come down.

4. **Chitty's theory** : Population is numerically self regulating through genetically induced changes in the average vitality of individuals associated with the change in population density. Individuals in a population vary in size, structure, physiology, fecundity and behaviour. When these variations are induced genetically the environmental factors tend to be selective in their action and gradually populations get adapted to environmental stresses.
5. **Pimental's theory** : A genetic feed back mechanism functions to regulate populations of herbivores, parasites and predators. For example in herbivore-plant system, animal density influences selective pressure on plants, this selection influences the genetic make up of the plant which in turn influences animal density.
6. **DeBach's theory** : He emphasized the influence of both non-biotic or physical factors and biotic factors on the rate of increase of a species and the variability of environments.

## 4.4 POPULATION DISTRIBUTION AND DISPERSAL

### ■ Population dispersal

The movement of individuals into or out of population is called dispersal. It takes place in search of food, to avoid predators, preventing over crowding due to wind, water, light or temperature conditions, breeding behavior and due to some physiological reasons.

The dispersal of population occur in 3 ways

1. Emigration
2. Immigration
3. Migration

#### 1. Emigration

It involves outward movement of organisms from one place or country to another for permanent settlement. This results in depopulation. Equilibrium population is maintained by enhancing the reproductive ability as well as by decreased mortality among the individuals.

**2. Immigration**

It is inward movement of the organism to any place or country. This will lead to a rise in population level, causing over population. Immigration results in increased mortality among the immigrants or decreased reproductive capacity of the individuals.

**3. Migration**

It involves mass movement of entire population. These movements take place during unfavourable conditions from the original area to other areas where conditions are favourable. These movements are generally seasonal or periodical.

Dispersal plays a great role in population dynamics by

- Dispersal helps in shaping population growth and density by supplementing natality and mortality
- New or depopulated areas are colonized by a population through dispersal leading to establishment of equilibrium density
- Dispersal helps to introduce genetic variability through interchange between populations
- Dispersal leads to an increase in the range of a species, thus enhancing the chances of genetic survival over evolutionary time

**■ Population structure**

Individuals of a population arrange themselves in manner that is specific to each population. The various structural aspects of a population are

- I. Dispersion
- II. Aggregation
- III. Isolation and territoriality
- IV. Intra - specific interactions

**I. Dispersion**

The distribution or physical location of individuals within a population at a particular time is called dispersion.

The distribution of individuals follows 3 broad patterns. They are

1. Random distribution
2. Uniform distribution
3. Clumped

1. **Random distribution** : The probability of locating individuals at a point in the populated area is equal for all the points. It is relatively rare in nature and it is expected to occur only when the environment is uniform and the resources are evenly spread.
2. **Uniform distribution** : It occurs where competition between individuals is severe and individuals are evenly spaced and tend to be as far apart from each other. Ex : Desert animals.
3. **Clumped** : The individuals of a population are found scattered in a groups here and there. This is most common pattern of distribution and result from non uniformity of the habitat or attraction among individuals. Ex : Bees.

## II. Aggregation

Clumping is the result of aggregation. The extent of aggregation in any population depends on the specific nature of habitat, weather or other physical conditions, reproductive pattern, characteristic of the species and degree of sociality. Aggregation leads to intra - specific competition for space, food and reproduction etc.

## III. Isolation and territoriality

Isolation usually is the result of either inter individual competition for resources in short supply, or direct antagonism. The territory of an organism is established prior to mating and hence it must contain surplus food so that newly born individuals can be fed.

## IV. Intra - specific interactions

Population distribution is governed by aggregation and isolation which are intimately related with interactions between the individuals of a population. Competition and antagonism are most important interactions.

# 4.5 BIOGEOGRAPHY

The word *Biogeography* is an amalgamation of Biology and Geography. Biogeography is a synthetic science, related to geography, biology, soil science, geology, climatology, ecology and evolution.

Biogeography is the comparative study of the geographic distribution of organisms and the corresponding evolution of their traits in space and time.

Biogeography is the study of the distribution of species spatially and temporally. It aims to reveal where organisms live, and at what abundance. The patterns of species distribution across geographical areas can usually be explained through a combination of historical factors such as speciation, extinction, continental drift,

glaciation and river capture, in combination with the area and isolation of landmasses (geographic constraints) and available energy supplies.

Modern biogeography employs the use of Geographic Information Systems (GIS), to understand the factors affecting organism distribution, and to predict future trends in organism distribution.

Fundamentals in biogeography are

- Evolution (change in genetic composition of a population)
- Extinction (disappearance of a species)
- Dispersal (movement of populations away from their point of origin, related to migration)
- Range and distribution
- Endemic areas
- Vicariance (splitting of lineages in a species)

Biogeography has a long history in the natural sciences where questions arise concerning the spatial distribution of plants and animals. Ecology and evolution provide the explanatory context for biogeographical studies. Biogeographical patterns result from ecological processes that influence range distributions, such as migration and dispersal.

### ***r* / *K* - Selection theory**

*r* / *K* selection theory, one of the first predictive models in ecology used to explain life-history evolution.

The premise behind the *r*/*K* selection model is that natural selection pressures change according to population density. For example, when an island is first colonized, density of individuals is low. The initial increase in population size is not limited by competition, leaving an abundance of available resources for rapid population growth. These early phases of population growth experience *density-independent* forces of natural selection, which is called *r*-selection. As the population becomes more crowded, it approaches the island's carrying capacity, thus forcing individuals to compete more heavily for fewer available resources. Under crowded conditions the population experiences density-dependent forces of natural selection, called *K*-selection.

In the *r*/*K*-selection model, the first variable *r* is the intrinsic rate of natural increase in population size and the second variable *K* is the carrying capacity of a population. Different species evolve different life-history strategies spanning a continuum between these two selective forces.



## 4.6 INSECT BIODIVERSITY

The term's biodiversity was coined by W.G. Rosen (1985).

Biodiversity is the variety and differences among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part. This includes genetic diversity within and between species and of ecosystems. Thus, in essence, biodiversity represents all life.

There are many ways to index, measure, and represent biodiversity. Biodiversity includes species diversity, ecosystem diversity, genetic diversity and the complex processes operating at and among these respective levels.

Biodiversity is the degree of variation of life forms within a given ecosystem, biome, or on an entire planet. Biodiversity is one measure of the health of biological systems.

Insects and related arthropods make up more than 50 percent of the known animal diversity globally. A better understanding of the biology and ecology of insects is the only way to sustainable manage ecosystems in an ever changing global environment.

Insects make up most of the worlds biodiversity. Of all the 1.7 million species described, approximately 45,000 are vertebrates, 250,000 are plants and 950,000 (56%) are insects. Of the estimated number of species in the world, 64% are insects. The most diverse order of insects described is the Coleoptera (400, 000 species: 24% of all species) followed by the Lepidoptera (9 %), Hymenoptera (8 %) and Diptera (7 %). Insects are not only more numerically diverse than other organisms; they also perform a disproportionate number of functional roles such as herbivory, predation, parasitism, decomposition, pollination etc.

## 4.7 BIOTIC POTENTIAL AND ENVIRONMENTAL RESISTANCE

### ■ Biotic potential

Biotic potential is the maximum reproductive capacity of a population if resources are unlimited. It is generally only reached when environmental conditions are very favourable.

A species reaching its biotic potential would exhibit exponential population growth and said to have a high fertility and thus many offsprings are produced per mother.

Biotic Potential is a fundamental species characteristic, it is “the inherent power of organisms to reproduce and survive”.

It is related to a “vital index”:

Vital Index = (number of births / number of deaths) × 100

Biotic potential is the highest possible vital index of a species; therefore, when the species has its highest birthrate and lowest mortality rate.

The maximum biotic potential of the species is the greatest number of offspring that could be produced in one generation under ideal conditions.

In ecology, the symbol “R” is known as the replacement rate. It is a way to measure the change in reproductive capacity from generation to generation. The value of “R” is simply the number of reproductive daughters that each female produces over her lifetime

$R = \text{Number of daughters} / \text{Number of mothers}$

- If the value of “R” is less than 1, the population is decreasing — if this situation persists for any length of time the population becomes extinct
- If the value of “R” is greater than 1, the population is increasing — if this situation persists for any length of time the population will grow beyond the environment’s carrying capacity
- If the value of “R” is equal to 1, the population is stable — most natural populations are very close to this value

#### ➤ **Carrying capacity**

It is defined as the capacity of environment or an ecosystem to support and sustain a level of population under an ideal set of conditions. Carrying capacity is a ceiling of population, beyond which the environment fails to support the population leading to natural decrease in population.

#### ➤ **Environmental resistance**

Full expression of the biotic potential of an organism is restricted by environmental resistance, any condition that inhibits the increase in number of the population. Environmental resistance is the effect of physical and biological factors in preventing a species from reproducing at its maximum rate.

Also referred to as population regulation, it means the total of all inhibitory factors naturally regulating the growth of population.

## 4.8 ECOSYSTEMS

### ■ Ecosystems

The various types of ecosystems in the biosphere are

- |                          |                            |
|--------------------------|----------------------------|
| 1. Terrestrial ecosystem | 2. High altitude ecosystem |
| 3. Aquatic ecosystem     | 4. Agro ecosystem          |

#### 1. Terrestrial ecosystem

It comprises of major biomes such as the deserts, high altitude and forests. The soil influences the type of vegetation, supply of nutrients and source of incorporation of detritus food chain. The abundance of insects in soil depends on the type of soil, the composition of microflora, soil moisture and type of vegetation.

Desert constitute the most extreme of all terrestrial communities, demanding special adaptations, viz., morphological, physiological and ethological from the inhabiting populations. In hot deserts the plant populations are mostly xerophytic. Acclimatization of desert inhabitants through diverse adaptations has resulted in a fauna capable of withstanding the rigours of the arid environment. Insects adapt diurnal rhythms to avoid heat.

#### 2. High altitude ecosystem

The important factors of high altitude environment are low air density, low oxygen, low carbon dioxide contents, water vapour, high ozone content, greater passage of light, snow cover, increased rate of desiccation, high wind velocity, exposure to high intensity of sun's rays during the day and rapid radiation during the night and absence of trees. Insects having shorter developmental period are more prevalent. Coleopteran insects belonging to families such as Carabidae, Staphylinidae, Tenebrionidae and Curculionidae are found here.

The forests of the world principally comprise major biomes such as tropical forests, temperate deciduous forests and coniferous forests. Tropical rain forests due to their richness of vegetation a large number of insect belonging to Heteroptera, Orthoptera, bees, termites, and ants are found here. In temperate deciduous forests, trees shed off their leaves during winter and bears leaves during summer. Some termites and larvae of wood boring insects are found here. The density and diversity of animals in grassland communities depend upon the thickness or sparseness of vegetation. Grasshoppers and termites are found in this biome. Bees, burrowing wasps, mutilid wasps, bumblebees and blister beetles are also found here.

### 3. Aquatic ecosystem

The amount of dissolved oxygen in a water body is frequently the key substance in determining the extent and kind of organic life in the water body.

There are three basic types of freshwater ecosystems:

- Lentic : Slow - moving water, including pools, ponds, and lakes.
- Lotic : Rapidly - moving water including streams and rivers.
- Wetlands : Areas where the soil is saturated or inundated for at least part of the time

Aquatic or semi-aquatic insects are springtails, mayflies, dragonflies, damselflies, stoneflies, bugs, flies and caddisflies. Aquatic insects must get oxygen while they are under water. In these insects spiracles are connected to tracheal tubes where oxygen can be absorbed. All aquatic insects have become adapted to their environment with the specialization of these structures.

Aquatic adaptations in insects are

1. Simple diffusion over a relatively thin integument
2. Breathing from a plastron or physical gill
3. Extraction of oxygen from water using a plastron or physical gill
4. Storage of oxygen in hemoglobin molecules in hemolymph
5. Taking oxygen from surface via breathing tubes (siphons)

Some insects have densely packed hairs (setae) around the spiracles that allow air to remain near, while keeping water away from, the body. They may even carry a bubble of air down from the surface. Others have a plastron that can be various combinations of hairs, scales, and undulations projecting from the cuticle, which hold a thin layer of air along the outer surface of the body. The trachea open through spiracles into this air film, allowing access to oxygen.

Lakes are different from running water and show conspicuous variations of various physicochemical with the changing day, year or season. In lakes, the water depth tends to restrict both plants and insect population distribution. Some dipterans survive in deep water.

### 4. Agro ecosystem

Although agro ecosystems may be greatly simplified compared to natural ecosystems, they can still foster a rich array of population and community processes such as herbivory, predation, parasitization, competition, and mutualism. Crop plants may compete among themselves or with weeds for sunlight, soil nutrients, or water. Agro ecosystem vary widely in stability, complexity and the area they occupy. Factors affecting the degree of stability of an agro ecosystem are

- Kind of crops
- Agronomic practices
- Changes in land use patterns
- Total complexity and self sufficiency
- Weather

Agricultural environment tends to be unstable because of cultural practices and ecological simplification. As a result most crop pests have a high degree of mobility and are highly adapted to colonizing due to changing or temporary agricultural environments. Stability of an agro ecosystem demands complexity in the area which in turn depends on the number and kind of trophic interactions.

There is a general tendency towards stability and complexity in perennial and mixed planting than to annual crop planting and monocultures. There will greater stability in uniform physical environments compared to those fluctuating markedly with the seasons and in old undisturbed ecosystems compared to new disturbed agro ecosystems.

There is also greater stability in the development of an agro ecosystem, there is tendency to organize and simplify the environment to maximize the yield by eliminating competition through control of weeds, diseases and arthropods. As a result complex food chains are changed into simple and short food chains leading to ecological succession at an early stage. The modern agro ecosystem are so simplified that a continued succession of pests out break is expected.

➤ **Agro - ecosystem analysis**

Agro - ecosystem analysis is a methodology for zoning and analyzing agricultural systems in order to plan and prioritize research and development activities in the fields of agriculture and natural resource management. It uses a holistic or systems approach to gather bio-physical and socio-economic information and, within the ecosystem, to identify key issues or problems that will be useful for rural development, extension and research programmes.

The analysis relies heavily on secondary data, both bio-physical and socio-economic information. Examples of bio-physical data are topography, climate, water resources, geology, soils, communications, infrastructure, and land use. Examples of socio-economic data are agriculture systems, agro-forestry systems, ethnicity and markets.

## 4.9 ECOLOGICAL NICHE

### ■ Ecological niche

The word “niche” meaning *to nest*. The term was coined by Joseph Grinnell (1917). The niche is the set of biotic and abiotic conditions in which a species is able to persist and maintain stable population sizes.

Niche is a term describing the relational position of a species or population in its ecosystem. The ecological niche describes how an organism or population responds to the distribution of resources and competitors and how it in turn alters those same factors.

The ecological niche is a central concept in the ecology of organisms and is sub-divided into

1. Fundamental niche
2. Realized niche

The fundamental niche is the set of environmental conditions under which a species is able to persist.

The realized niche is the set of environmental plus ecological conditions under which a species persists.

### ➤ The concept of the ecological niche

- The ecological niche of a species is defined as the functional role of the species in its community and the position of the species along all environmental gradients (ecological amplitude).
- The fundamental niche is the full space which a species can occupy according to all its environmental gradients.
- The realized niche is a small space occupied by the species in the face of competition from all other species.
- The spatial distribution of a species is a good indicator of its realized niche, but the position of the species within the ecological pyramid must also be considered.

The concept of niche has been extended to categories such as spatial niche, habitat niche, trophic niche or climatic niche, etc. Organisms totally unrelated to each other yet occupying identical niches in widely separate areas or geographical ranges but almost identical in appearance and basic adaptations are called ecological equivalents.

According to the competitive exclusion principle, no two species can occupy the same niche in the same environment for a long time. This is known as Gause's rule.

## 4.10 LIFE TABLE

### ■ Life table

Life table concept was first formulated by Raymond Pearl (1924).

Morris and Miller (1954) were the first to adopt the life table format for the study of natural insect populations. They studied in the spruce budworm, *Choristoneura fumiferana*

Life table is the systematic tabulation of births and deaths of an organism. It is summary statement on the life of a typical individual of population or a cohort of individuals.

A typical life table contains

$x$  = Age of cohort

$d_x$  = Number dying at age interval

$l_x$  = Number surviving at the beginning of age interval

$1000 q_x$  = Mortality rate (per thousand) at the beginning of age interval or  $d_x$  as a percentage of  $l_x$

$e_x$  = Expectation of life or mean life time remaining to those attaining age interval

The age interval  $x$  is into life stages i. e. egg, larval stages, pupae and adult and additional column  $d_x F$  was added the factor responsible for  $d_x$ . This  $d_x F$  column takes into account all the mortality factors that could be quantified and the  $d_x$  and  $1000q_x$  column take into account actual values for each of these factors

| $x$          | $l_x$                         | $d_x F$                      | $d_x$                | $1000 q_x$                   |
|--------------|-------------------------------|------------------------------|----------------------|------------------------------|
| Age interval | No. alive at beginning of $x$ | Factor responsible for $d_x$ | No. dying during $x$ | $d_x$ as percentage of $l_x$ |

If the logarithm of number of a species is plotted against time or age a curve called survivorship curve is produced. The shape of the curve is an indication of the mortality distribution with age.

Three types of curves are recognized. They are

1. Type I curve : It shows a very low death rate of young and high mortality in old age. Ex : Higher vertebrates and *Drosophila*

2. Type II curve : It is straight line survivorship curve. Ex : Birds, Hydra and bacteria
3. Type III curve : In this curve huge mortalities occur in early stages. Ex : Parasitic organisms.

Life tables are of two types

- a. Age dependent
  - b. Stage dependent
- a. Age - dependent life - tables :** Age - dependent life table shows organisms' mortality (or survival) and reproduction rate (maternal frequency) as a function of age. In nature, mortality and reproduction rate may depend on numerous factors : temperature, population density, etc. When building a life-table, the effect of these factors is averaged. Only age is considered as a factor that determines mortality and reproduction. Only females are considered in this life-table.
- b. Stage - dependent life tables :** These are used mainly for insects and other terrestrial invertebrates.

Stage - dependent life tables are built in the cases when:

- The life - cycle is partitioned into distinct stages (e.g., eggs, larvae, pupae and adults in insects)
- Survival and reproduction depend more on organism stage rather than on calendar age
- Age distribution at particular time does not matter (e.g., there is only one generation per year)

### Advantages and limitations of life tables

#### Advantages

- Life tables provide age specific data which are ideal for use in population management
- It gives information about population trend in relation to environment factors
- It helps in reducing the outbreaks of insects pests by altering the factors
- Useful for insects having one generation and little overlapping of developmental stages

#### Limitations

- Sampling of different developmental stages of same insects at different locations is very difficult
- It is not useful for insects having widely overlapping stages and generations



## 4.11 FOOD CHAIN AND FOOD WEB

### ■ Food chain

Food chains and food webs are representations of the predator-prey relationships between species within an ecosystem or habitat.

The energy stored by plants is passed along through the ecosystem in a series of steps of eating and being eaten. This is called as food chain.

Ex : Sun → plant → grasshopper → frog → snake → hawk

### Food web

The concept of the food web was introduced by Charles Elton (1927).

A food web is a series of related food chains displaying the movement of energy and matter through an ecosystem. There are many food chains contained in food webs.

The food web is divided into two broad categories:

1. The grazing web, beginning with autotrophs

Ex : Green plants → herbivores → carnivores

2. The detrital web, beginning with organic debris

Ex : Dead organic matter → microbes → detritivores → predators of detritivores

A food web is a graphical description of feeding relationships among species in an ecological community, that is, of who eats whom. It is also a means of showing how energy and materials flow through a community of species as a result of these feeding relationships. Typically, species are connected by lines or arrows called “links”, and the species are sometimes referred to as “nodes” in food web diagrams.

A food web differs from a food chain in that the latter shows only a portion of the food web involving a simple, linear series of species (e.g., predator, herbivore, plant) connected by feeding links.

A food web aims to depict a more complete picture of the feeding relationships, and can be considered a bundle of many interconnected food chains occurring within the community.

All species occupying the same position within a food chain comprise a trophic level within the food web. For instance, all of the plants in the food web comprise the first or “primary producer” trophic level, all herbivores comprise the second or “primary consumer” trophic level, and carnivores that eat herbivores comprise the third or “secondary consumer” trophic level. Additional levels, in which carnivores eat other carnivores, comprise a tertiary trophic level.

Food chains tend to show characteristic patterns of increasing body size as one moves up the food chain. Because individuals of small-bodied species require less energy and food than individuals of larger-bodied species, a given amount of energy can support a greater number of individuals of the smaller-bodied species. Hence, ecological communities typically show a pyramid of numbers (also called as Eltonian pyramid), in which the species at lower trophic levels in the food web tend to be more numerous than those at higher trophic levels.

## 4.12 PEST SURVEILLANCE / MONITORING

### ■ Pest surveillance

Pest surveillance is the watch kept on a pest for the purpose of decision making. Depending on the kind of pest, surveillance programs attempt to determine if a pest species is present, to estimate the numbers in a population and their distribution and to assess how these factors change over time.

The major objective of surveillance is detection of species presence and determination of population density, dispersion and dynamics

Pest surveillance comprises of 3 basic components namely

1. Determination of the level of incidence of the pest species
  2. Determination of what loss the incidence will cause
  3. Determination of economic benefits or other benefits the control will provide
- Surveillance can provide the necessary information to determine the feasibility of a pest control programme.

Regular field surveillance (= monitoring) is an important component of integrated pest management (IPM). Surveillance helps prognosis i. e. foreseeing the population of pests, their interaction with natural enemies and the resultant effect

It is essential for the following activities associated with IPM

- a. Ecological characterization of an area
- b. Acquaintance with pests, disease and beneficial insects
- c. Assessment of critical density
- d. Crop loss assessment

The most successful surveillance programs carried out by the agencies are achieved through regular survey activities. An insect pest survey is a detailed collection of insect population information at a particular time in a given area.

The survey program may be carried on for a entire growing season or at certain critical periods in the insect life cycle. The area involved in a survey may be small as field, or it may be as extensive as state or region of the country.

Surveys are classified into 2 types. They are

1. Qualitative survey
2. Quantitative surveys

1. **Qualitative survey** : It involves the identification of the different species of a region. Qualitative surveys may also be limited to one or more of the following categories such as potential pests, actual pests and natural enemies, abundance etc.
2. **Quantitative surveys** : It involves the measurement of the abundance of an insect. These are of two types. i). Absolute and ii). Relative. Quantitative is more efficient to estimate population density by sampling.

## 4.13 SAMPLING

### ■ Sampling

A sampling technique is the method used to collect information for a single sample. A sampling program is the procedure for employing the sampling technique in time and space.

Measurement taken to estimate population density (sampling methods) fall into 3 groups

- I. Absolute methods
- II. Relative methods
- III. Population indices

#### I. Absolute methods

Absolute methods yield estimates as densities per unit area of land area in the habitat.

Four distinct approaches have been used in Entomology to estimate absolute population densities. They are

- a. The distance to nearest neighbour approach
- b. Sampling a unit of habitat
- c. The recapture of marked individuals

d. Removal trapping

**a. The distance to nearest neighbour approach**

This method is based on randomly selecting an individual and then measuring the distance to its nearest neighbour. It is commonly used for sessile insects (scale insects).

$$m = (Pr)^{-2}$$

where m is the density for unit area

r is the mean distance between nearest neighbour

P is the index of aggregation

P = 2 for randomness

P > 2 for aggregate distribution

**b. Sampling a unit of habitat**

The main advantage of this approach is its broad range of applicability. It makes no assumptions about the spatial distribution of the species nor about its activity or behaviour.

The disadvantage of this approach lie largely in the processing of the samples. How samples are acquired from air, vegetation, soil and litter

**i. Sampling from air :** Suction traps and rotary traps are the two basic methods used. The advantage of the rotary trap is that catch is independent of wind speed. Since the catch with these traps is almost exclusively insects, there is no problem in counting the number per sample. The total aerial population 'P' can be calculated if density estimates are available for at least 3 heights.

**ii. Sampling from vegetation :** Two essentially distinct approaches are used for estimating absolute density from vegetation. The most direct method is to sample all plant matter over a unit area of soil surface. The alternate approach is to use a plant or plant part, such as branch or leaf, as the sample unit. It then becomes necessary to determine the density of these sample units per unit of land area. The absolute population density is then the product of the number of insects per sample unit and the number of sample units per unit of land area.

A technique often used in sampling insects from vegetation involves placing a collecting sheet on the ground beneath the plant or area being sampled and then knocking the insects off the plant onto the sheet by physically beating the vegetation or by using a chemical knockdown agent such as aerosol pyrethrin.

**iii. Sampling from soil and litter :** Only one technique is used of sampling from soil and litter namely digging up a unit area to a predetermined depth. If the insect being sampled is fairly abundant, quite small and possibly several

centimeters deep in the soil, the best sampling device is a core sampler.

If the insect is larger and is found in the litter or in the top 1 cm of soil, then it is better that the sample unit of a larger area and of a lesser depth. A square meter or square foot of litter plus the top 1 cm of soil is a reasonable sample unit

- iv. Extracting the insects from the sample:** Separating the insects being studied from the other material in the sample may involve many hours of hand sorting and shifting. Although hand sorting is very time consuming and tedious work but it is efficient.

An often used alternative to hand sorting is to place the samples in a Berlese funnel and to expel the insects using a heat source such as an incandescent light, into a vial of alcohol.

**c. Recapture of marked individuals**

The simplest way to use recapture data was proposed by Lincoln and is called Lincoln Index. This method requires additional assumptions that no births, deaths, immigration or emigration occur between the time of releasing the marked animals and the subsequent recapture sampling.

The total population size 'P' can be computed from the numbers marked and released 'a'

The total number of individuals taken in the recapture sampling 'n' and the number of marked individuals recapture 'r' by use of equation

$$P = an / r$$

The best estimate of 'P' is obtained when 'a' and 'n' are approximately equal.

**d. Removal trapping**

Removal trapping is based on the fact that as the population is reduced by removing members from it, the catch per trap per unit time decreases. The simplest method is to plot the number caught in the 'n'<sup>th</sup> sampling against the previous total catch and to draw a straight line through these points. An estimate to the initial population size is then obtained by reading from the graph the value at which the line intersects the total catch axis. Removal trapping is rarely used in Entomology

## **II. Relative methods**

Relative methods yield densities per some unit other than land area and can not be converted to absolute estimates. The sweep net and black light trap are two of the most common methods used to sample insect population densities.

Relative methods have distinct advantage over absolute methods, a given amount of labour and equipment yields much more data.

The factors that affect the catch of any relative method are

- a. The actual density or population size
- b. The number of insects in a particular stage
- c. The level of activity
- d. The efficiency of the relative method being used
- e. The responsiveness of the particular sex and species to the trap stimulus

Relative methods can be divided into two broad classes

1. Catch per unit effort
2. Trapping

### 1. Catch per unit effort

- a. Visual searchers
- b. Sweep net
- c. D - vac (Suction net)
- d. Shaking and beating (Ground cloth)

**a. Visual searchers :** Visual searching an area may be considered an absolute measurement of population size, but in general less than 100% of the insects present are found. The proportion found may vary with condition, thus making the relationship between absolute population and catch unpredictable.

**b. Sweep net :** It is the most often used method for sampling insects from small grain, forage and many row crops. The reason is no other method can capture as many insects per man hour without both costing more for the equipment and doing more damage to the crop.

The efficiency of the sweep net usually varies with the type of species, habitats, weather, time and style of sweeping.

**c. D - vac (Suction net) :** A device with trade name D-vac captures insects by sucking them into a fine mesh net held open inside a rigid enclosure. A portable gasoline motor propels a blower that generates the suction. This device is most useful for small light bodied species such as leaf hopper adults and parasitic Hymenoptera.

**d. Shaking and beating (Ground cloth) :** The ground cloth is the most widely used method in row crops. This method consists of spreading a piece of heavy cloth on the ground along the stems of the plants to be sampled. The plants are bent over the cloth and vigorously shaken or beaten with a wooden stick. The insects dislodged from the plant fall on the cloth and are collected and counted.

### 2. Trapping

- a. Malaise traps
- b. Window pane traps
- c. Sticky traps
- d. Pit fall traps
- e. Visual traps
- f. Traps using attractants

- a. **Malaise traps** : A malaise trap essentially consists of a tent made of netting with one open side into which insects either fly or crawl. Since, most insects automatically crawl up the netting they can be trapped in vials of preservative placed in the upper corners. Since these traps depend upon the insects to enter them accidentally they work best for highly active species such as adult Diptera and Hymenoptera.
- b. **Window pane traps** : Flying Coleoptera can be sampled using window pane traps, which consists simply of a vertical pane of glass or Plexiglas with a trough of preservative beneath it. Any insect that hit the glass and reacts by falling is caught. These traps are particularly useful for determining direction of flight and can also provide data as to when dispersal flight occur.
- c. **Sticky traps** : Sticky traps are conveniently thought of as variation of window pane traps in which glass, screening wire or some other surface is covered with some substances sticky enough to hold the insect where it hits rather than allowing it to fall into the preservative. Sticky traps can be used for many species that can not be taken with window pane traps. Since, the insects are caught in place, the sticky substances can be put on almost anything and anywhere. Often these traps are combined with baits or attractants to enhance the catch of certain species.
- d. **Pit fall traps** : Pit fall traps are used for species that roam on the soil surface, such as ground beetles, spiders and Collembola. When used with out baits, they catch what over accidentally falls in, when baited, they draw individuals from considerable distances. Traps baited with beer are often recommended control practice for slugs in the home gardens.
- e. **Visual traps** : The most common devices using visual attraction are light traps. A typical light trap has an ultraviolet fluorescence tube above a collecting jar containing a killing agent. These traps have been used mostly for moths and mosquitoes and restricted to species that fly at night or at twilight.
- f. **Traps using attractants** : Species that are not attracted to light may be trapped instead by using a sticky board in combination with and attractant or bait. Pheromones are often used for this purpose.

### III. Population Indices

Population indices do not count insects at all but rather are measures of insect products such as plant damage, frass or nests.

In some cases a species that is difficult to sample directly creates products that are easily sampled by absolute methods. The insect product most often sampled is the frass or excreta of Lepidopterous defoliators of forests. The rate at which frass is being produced can be estimated from the amount falling into box or funnel

placed under the trees.

The size and shape of the frass pellet are rather constant for given species and instar, this allows one to identify the species and age composition of the defoliators with out seeing the insect.

## 4.14 PEST FORECASTING

### ■ Forecasting

Forecasting is the prediction of the type of fluctuation which will ensue.

Forecasting pest incidence often requires systematically recorded specific field data in an elaborate manner over considerable period of time which can be easily retrieved and analyzed.

Insect forecasting service may thus serve :

1. To predict the forth coming infestation level of the pest, which knowledge is essential in justifying use of control measure mainly insecticidal application
2. To find out the critical stage at which the application of insecticides would afford maximum protection

**The forecasting is mainly of two kinds**

1. **Short time forecasting** : It covers a particular season or one or two successive seasons only and is usually made employing insect trapping methods or some other sampling of the pest with in the crop
2. **Long time forecasting**: It covers large areas and based mainly on the possible effects of weather on the insect abundance or by extrapolating from the present population density into the future.

The forecasting of pest population must be related to economic threshold of the pest and can be made through.

#### a) Population studies (quantitative studies)

These studies should be carried out over several years using appropriate sampling methods to find out the seasonal range the population variability and geographic distribution. The seasonal counts should be related to the climatic and topographical data.

#### b) Studies on the pests life history

The possible number of generations and the behaviour of the different larval instars, the length of the life cycle both in the field and in the laboratory can be related to the range of environmental factors such as temperature, humidity etc.,

#### c) Field studies of the effects of climate on the pest and its environment



Climate factors usually influence pest numbers and also its parasites and predators either directly or indirectly.

The available methods of pest forecast can be classified into 3 categories

**1. Forecasting based on observations of environmental factors**

Of the different environmental factors, temperature and rainfall are most commonly used in pest forecasting.

Ex : The amount of rainfall is used to determine the emergence of moths of *Amsacta albistriga* and *Amsacta moorei*.

**2. Forecasting based on observations of climatic areas**

Areas where critical infections are likely to occur can also be forecasted for some pests. The principal factors may be biotic, topographic or climatic. Combination of temperature and rainfall, temperature and atmospheric humidity in case of soil insects, soil temperature and soil moisture content are the most important.

The geographical distribution of some pests is controlled by certain limiting climatic factors.

**3. Prediction from empirical observations:** Attempts have been made to forecast the population of the insect pests in the next season by counting the pest in the previous seasons.

## 4.15 DIAPAUSE

### ■ Diapause

Diapause is a suspension of development that can occur at the embryonic, larval, pupal, or adult stage, depending on the species. Diapause is an important means by which insects avoid unfavorable environmental conditions.

Examples of sensitive stage / diapause periods in various insects

- Silkworm – Embryonic
- Grasshopper – Egg
- Gypsy moth – Late embryonic (Embryo)
- Southwestern corn borer – Late larval
- Tobacco hornworm – Pupa
- Cabbage white butterfly – Pupae
- Colorado potato beetle – Adult

- Monarch butterfly – Adult

Diapause is of 2 types

1. Facultative diapause
2. Obligatory diapause

### 1. Facultative diapause

In some species, diapause occurs only when induced by environmental conditions. Diapause affects only some members of a generation resulting in two or more generations in a year (multivoltine).

### 2. Obligatory diapause

In some species the diapause period has become an obligatory part of the life cycle. Every individual in every generation enters diapause in obligatory diapause resulting in only a single generation (univoltine).

#### Initiation of diapause

The period of day light (photoperiod) is a most important factor in inducing diapause. Other factors are temperature, food, and age of the parent.

#### Photoperiod

The day length when 50% of the population has entered diapause is called the critical day length. There is critical day length around which small differences in photoperiod produce a complete change from non-diapause to diapause development.

Long day insects: Insects entering diapause when the day length falls below the threshold are called long day insects.

Short day insects: Insects that develop normally when there are only a few hours of sunlight and that enter diapause when exposed to longer days are called short-day insects.

Ex : *Bombyx*

#### Temperature

Temperature also plays an important role in the induction of diapause. In temperate regions, high temperature inhibits and low temperature enhances diapausing tendencies. In *Bombyx* high temperature induces diapause and low temperature prevents it.

There is usually a build up of reserve food substances, particularly in the fat body with a consequent reduction in the proportion of water in the body. In temperate insects, during diapause there is accumulation of polyhydric alcohols, such as sorbitol and glycerol which can function as cryoprotectants.

**Control of diapause**

While diapause in the embryonic stage appears to be regulated (at least in some species) by a diapause hormone, larval diapause appears to be controlled by the inhibition of prothoracicotropic hormone (PTTH) production. This prevents the larvae from moulting and entering pupation. Similarly, the lack of PTTH and ecdysone secretion once pupation has occurred will cause diapause during this part of development. Diapause is controlled ecdysone in larval and pupal stages its deficiency resulting in arrestation of moulting and growth.

**4.16 CAUSES OF PEST OUTBREAKS****■ Ecological causes of pest outbreaks**

Insect pest population outbreaks are characterized by rapid change in population density over several orders of magnitude.

Two kinds of outbreaks that occur are

1. Introduction of a species to a new area
2. Growth of a native population

The population size of any organism can change only by four processes; birth, death, immigration, or emigration. The ecological causes of pest outbreaks must operate through increases in rates of birth, decreases in rates of death, increases in immigration, or decreases in emigration.

Insect outbreaks are usually the result of a combination of ecological factors. These are :

- a) Introduction of exotic species
- b) High yielding varieties
- c) Nutrients
- d) Pesticides
- e) Cultural practices
- f) Temperature
- g) Mono - culture of crops
- h) Introduction of plants to new locations
- i) Weather pattern
- j) Migration

- a) **Introduction of exotic species** : When exotic species are introduced into a new region in the absence of natural enemies, their natality may be high, while mortality is sufficiently reduced, causing population out break to occur.
- b) **High yielding varieties** : Due to high yield and growth provide plenty of food to the pest population leading to the quick multiplication of the pests.
- c) **Nutrients** : Indiscriminate use of fertilizers will lead to the good growth of the plant there by providing food to the insect pests.
- d) **Pesticides** : Indiscriminate use of broad spectrum insecticides have unduly resulted in an increase in the number of the pests by reducing the natural enemies.
- e) **Cultural practices** : Cultural practices which are favourable to the insects will lead to outbreak of the insects.
- f) **Temperature** : It is most important factor that governs the rate of growth and development of insects. The rate of development increases with the increase in temperature.
- g) **Mono - culture of crops** : Generally crop monoculture is more vulnerable to pest because there is less resistance and fewer natural enemies of the specific pests attacking the crop.
- h) **Introduction of plants to new locations** : Some pest problems occurs when crops are introduced into new biological communities.
- i) **Weather pattern** : For flying insects such as locusts, the prevailing winds are important in determining where they will fly and whether they will survive.
- j) **Migration** : Movement to a different area with more favorable conditions allows some pests species to escape control and increase in number.

#### 4.17 POLYMORPHISM

The existence of two or more forms of individuals within the same insect species is called polymorphism. The larva, pupa or adult represent different forms in a polymorphic insect. These forms may be color polymorphism, mimetic polymorphism, wing dimorphism (alate and apterous dimorphism or macropterous and brachypterous dimorphism), sexual and parthenogenetic forms and caste polymorphism. The control factors included genetic factors, endocrinal factors, exocrinal factors and environmental factors (light quality, light intensity, photoperiod, temperature, humidity, host, nutrition and population density). Caste polymorphism, defined as the presence within a colony of two or more morphologically differentiated individuals of the same sex,

is an important character of highly eusocial insects both in the Hymenoptera (ants, bees and wasps) and in the Isoptera (termites).

Polymorphism in some insects is governed by genetic while in other insects it is governed by environment in which insect develops.

Polyphenism refers to the occurrence of different phenotypes within a species where the development of the phenotype is governed by environmental conditions. Polyphenism is a characteristic feature of social insects where the different castes are determined by needs of the colony and in aphids where different morphs occur seasonally.

Dispersal polymorphism is important in understanding of dispersal *per se* in addition to understanding of population dynamics and species interactions, life history evolution and the physiological basis of adaptation. Dispersal polymorphism is a widespread phenomenon among the insects, occurring in the Orthoptera, Psocoptera, Thysanoptera, Homoptera, Heteroptera, Coleoptera, Diptera, Lepidoptera, and Hymenoptera.

There are two major categories of dispersal polymorphism :

(a) Wing polymorphism

(b) Flight muscle polymorphism.

Wing polymorphism, has been the most commonly studied type of dispersal polymorphism. Obligate flightless individuals (wingless or with reduced wings) can be visually identified in these species. Studies of wing polymorphism have also played a significant role in the development of ideas concerning the interaction between dispersal and other key life history traits such as fecundity, age at first reproduction, and diapauses. In numerous wing-polymorphic species, flight capability (presence of fully developed wings and flight muscles) is negatively correlated with age at first reproduction and fecundity. Such negative associations have led to the notion that flight capability and reproduction are energetically expensive and compete for internal resources, thus resulting in trade-offs (i.e. the flight-oogenesis syndrome).

Wing polymorphism involves discrete variation in the size of the wings and flight muscles, such as occurs in aphids and plant hoppers. Thus, in wing-polymorphic species, there is a flight-capable morph with fully developed wings (macropter or alate) and a flightless morph, either with reduced wings (brachypter) or without wings (apter).

In contrast, flight-muscle polymorphism involves variation in the size of flight muscles. In this case, all individuals are macropterous and the morph with reduced flight muscles is flightless.

- **Castes of social insects**

In Hymenoptera the queen and workers are females. In *Apis*, the newly hatched female larva has the potential to develop into either form. Its subsequent development is determined by the quality and quantity of food supplied to it. If given a diet based primarily on secretions of the nurse bees mandibular glands it will become a queen. If it receives larger proportions of secretion from the hypopharyngeal glands of the workers, it will itself become a worker. Similarly, among the larvae of worker ants, the differentiation of minor or major workers or of soldiers is dependent on feeding, which is ultimately reflected in the sizes of the larvae.

These size differences lead to different titers of juvenile hormone which controls the insects development. The switch from worker to queen in *Apis* is made in the late fourth and early fifth larval stages. Queen larvae develop a high titer of juvenile hormone late in the fourth larval stage, where in workers the titer is very low. In case of larval ants, major worker or soldier development is apparently the result of a high titer of juvenile hormone early in the final larval stage.

- **Aphid morphs**

Aphids occur in a variety of different forms. Most generations consist of entirely parthenogenetic females, but a sexual generation usually occurs each year. Some aphids have summer and winter hosts. Ex: *Aphis fabae*. Movement between the two hosts demands the production of winged morphs (alate or alates), whereas at other times the aphids are commonly wingless (apterae) although winged forms may also be produced on the secondary, summer host.

The sexual generation is usually produced in response to the short days of autumn acting on the parent aphid. Males are produced by the loss of an X chromosome during the single maturation division of the oocytes.

Under long photoperiods, the largest embryos in the ovarioles are determined for the production of more virginoparae (insects that will produce more parthenogenetic forms). Under short photoperiods, the embryos become determined as gynoparae (giving raise to sexual forms) or directly as oviparae (the sexual female). The production of virginoparae is stimulated by a neurosecretion from cells in the brain and juvenile hormone is also involved in virginoparae production.

- **Brachyptery in other insects**

Short winged forms are known to occur in many species of Orthoptera and Hemiptera. Long wings are often produced in response to crowding or poor food quality. The suppression of wing development is a response to high titres of juvenile hormone in final stage larvae.

- **Colour and Form**

Many insects exhibit colour variation in response to environmental changes. These may be regular occurrences as in the seasonal forms of some butterflies or more unpredictable as in the phenomenon of homochromy (The colour of many insects change to meet the predominant colour of the back ground). Crowding of larvae of some Lepidoptera and grasshopper causes them to become darker, or to have more dark patterning than sibling reared in isolation. This is due to deposition of greater quantities of melanin in the cuticle.

Many adult butterflies also exhibit seasonal colour polyphenism. Different colour morphs are produced by long or short days, acting in concert with the high or low temperatures. These environmental effects produce differences in the timing of ecdysteroid action sometimes synthesized by the action of a neuropeptide from the brain. Production of the different morphs is associated with the presence or absence of a pupal diapause.

## 4.18 ALTERNATION OF GENERATIONS

In several groups of insects, succeeding generations are quite different in method of reproduction, morphology, and sometimes in feeding habits. This is called *Alternation of generations*. Most of these have reproduction only by adults, although one generation may have sexual adults while the next may be parthenogenetic. A few have reproduction by adults and by immature forms. The life cycles are usually complicated, involving alternate hosts, winged and non-winged adults, different feeding patterns, etc. The aphids (Homoptera) and gall wasps (Cynipidae: Hymenoptera) are the most typical of these groups. Alternation of generations may also occur in Cecidomyiidae.

Alternation of generations is common in aphids. Ex: Soybean aphid

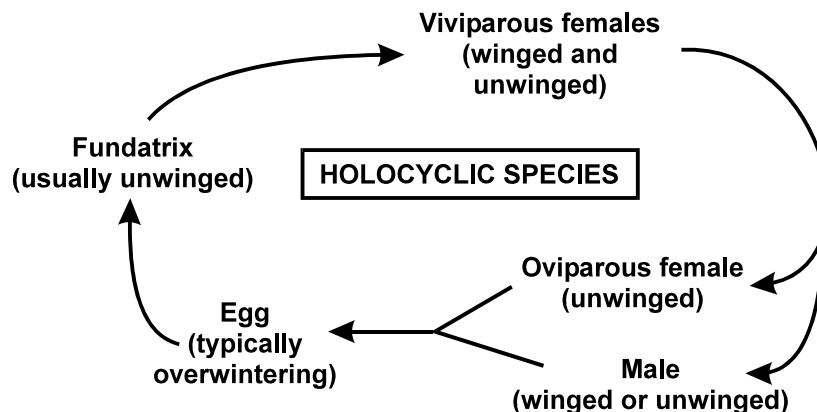
- Sexual and apomictic thelytokous forms appear in response to environmental cues
- Oviparous females and males in fall mate and produce eggs
- Eggs hatch into a wingless fundatrix in spring
- Fundatrix produces (viviparously) wingless daughters (fundatrigenia)
- Daughters produce generations of virginoparae
- Crowding and tactile stimuli acting on the mother late in the embryonic development of the daughters leads to production of alate (winged) forms, which disperse

- vii. As day length falls and temperatures moderate, both alate and apterous virginoparae may produce oviparae and males (males by loss of X chromosome to produce XO individuals)
- viii. In some species this cycle is accompanied by alteration of host plants

### • Alternation of Generations

Aphids undergo cyclical parthenogenesis - that is, the alternation of one or many generations of asexual (parthenogenetic) reproduction with a single generation of sexual reproduction. All asexual generations are entirely female. Species that produce both sexual and asexual morphs are holocyclic. When a species produces only asexual morphs it is anholocyclic.

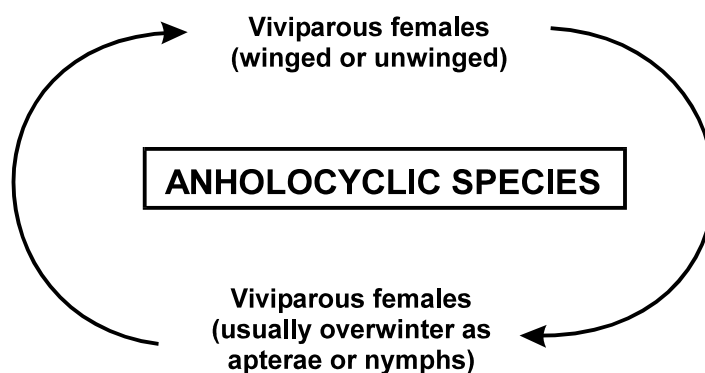
In a holocyclic life cycle, both asexual and sexual morphs are produced at different times of the year. Males are present only in one part of the life cycle. They are produced de novo by parthenogenetic females, usually only in the autumn. Aphids can accomplish this feat because they have an XO sex determining mechanism. Individuals with two sex chromosomes (XX) develop into females, whereas individuals with one X chromosome (XO) develop into males. To produce a male, a special “mini-meiosis”, which involves only the X-chromosomes, eliminates one of the X chromosomes during oogenesis.



In contrast, anholocyclic species only produce asexual females. They do not produce sexual females and males. Comparing the diagram of holocycly above, with the diagram of anholocycly below, notice that more than just the sexual males and females are missing from the anholocyclic species. In fact, anholocyclic species also lose the direct descendants of the sexual morphs, namely the egg and the



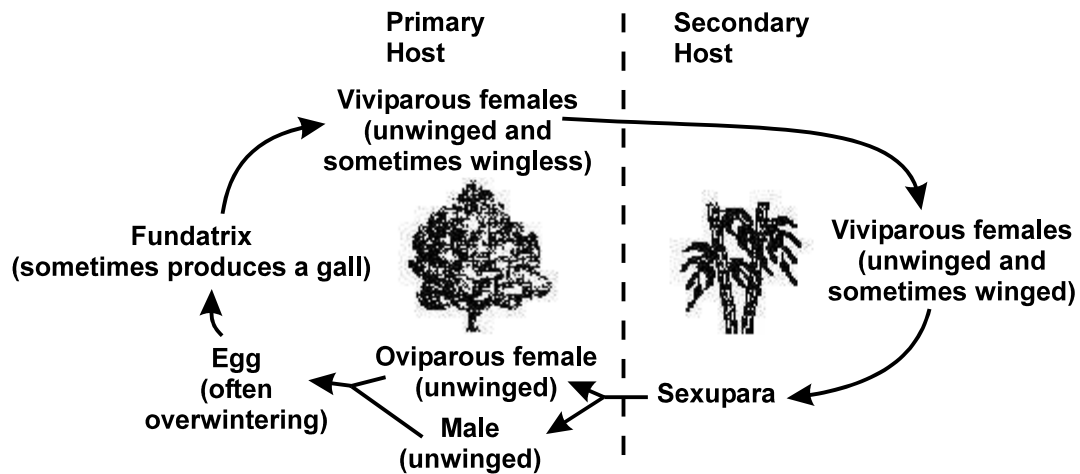
fundatrix. Since the fundatrix is often specialized for feeding on the primary host anholocyclic species often lose the primary host. Thus, simplification of the life cycle often, but not always, entails both loss of the sexual morphs and loss of host plants. Although many species are either holocyclic or anholocyclic, many other species possess both holocyclic and anholocyclic populations.



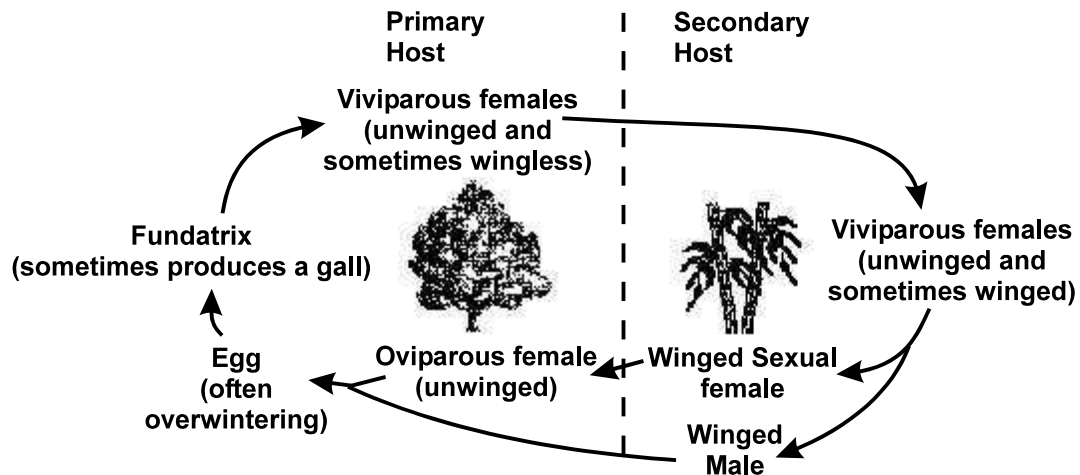
- **Host Alternation**

Many species of aphids alternate between two taxonomically different host plants at different times of the year. When an aphid species uses only a single host plant it is autoecious. Species that alternate between two host plants are called heteroecious. Two distinct kinds of heteroecious life cycles are found in aphids. Species of the Hormaphididae, Anoeciidae and Pemphigidae have a type of heteroecy with sexuparae. Other aphid species with host alternation do not have sexuparae, but have a life cycle with winged sexual females and winged males.

A typical life cycle of a heteroecious species from the Hormaphididae, Anoeciidae, or Pemphigidae is illustrated below. Aphids alternate between two taxonomically unrelated host plants. The primary host, a tree or shrub, is considered the “ancestral” host, in that the monoecious ancestor of aphid is thought to have attacked such trees. The secondary host is often an herbaceous plant. A specialized winged morph, the sexupara, flies from the secondary host to the primary host and deposits sexual males and females. The males and females mate and the female typically produces a single egg. In temperate regions the egg overwinters and produces the fundatrix, or foundress, in the spring. In many species the fundatrix induces abnormal plant development that results in a gall in which the colony lives for one or several generation.



Some species of the Aphididae have a different kind of host alternation, as illustrated below. The primary difference is that sexuparae are not produced. Instead, winged males and specialized winged females depart from the secondary host. The females produce unwinged oviparous females that mate with the winged males.



## 4.19 WOLBACHIA

*Wolbachia* is a genus of bacteria which infects arthropod species, including a high proportion of insects and some nematodes. It is one of the world's most common parasitic microbes and is possibly the most common reproductive parasite in the biosphere. Its interactions with its hosts are often complex, and in some cases have evolved to symbiotic rather than parasitic. 20% of all insect species harbor heritable symbionts called *Wolbachia*. These are cytoplasmically inherited rickettsiae that are found in reproductive tissues (ovaries and testes) of a wide range of arthropods.

The genus was first identified in 1924 by Marshall Hertig and S. Burt Wolbach in *Culex pipiens*, a species of mosquito. Hertig formally described the species in 1936 as *Wolbachia pipientis*.

*Wolbachia* is notable for significantly altering the reproductive capabilities of its hosts. These bacteria can infect many different types of organs, but are most notable for the infections of the testes and ovaries of their hosts.

*Wolbachia* species are known to cause four different phenotypes:

- **Male killing** : males are killed during larval development, which increase the rate of born females.
- **Feminization** : infected males develop as females or infertile pseudo-females.
- **Parthenogenesis** : reproduction of infected females without males. Some scientists have suggested that parthenogenesis may always be attributable to the effects of *Wolbachia*. An example of a parthenogenic species is the *Trichogramma* wasp, which has evolved to procreate without males with the help of *Wolbachia*. Males are rare in this tiny species of insect, possibly because many have been killed by that very same strain of *Wolbachia*.
- **Cytoplasmic incompatibility (CI)** : the inability of *Wolbachia*-infected males to successfully reproduce with uninfected females or females infected with another *Wolbachia* strain. *Wolbachia*-induced CI is a reproductive incompatibility between sperm and egg, which typically results in zygotic death in diploid species or male production in haplodiploid species. The bacteria are transmitted in eggs but are not transmitted through sperm. CI takes two forms, unidirectional and bidirectional. Unidirectional incompatibility typically occurs when the sperm from a *Wolbachia*-infected male fertilizes an uninfected egg. The reciprocal cross (uninfected male and infected female) is compatible. Bidirectional incompatibility typically occurs when a male and a female harbor different strains of *Wolbachia* that are mutually incompatible.

Several species are so dependent on *Wolbachia*, they are unable to reproduce effectively without the bacteria in their bodies. *Wolbachia* species are present in mature eggs, but not mature sperm. Only infected females pass the infection on to their offspring.

*Wolbachia* have attracted considerable recent interest for several reasons.

- First, given their widespread distribution and effects upon hosts, *Wolbachia* have implications for important evolutionary processes. Of particular interest is their potential role as a mechanism for rapid speciation.
- Second, these intracellular bacteria are known to alter early development and mitotic processes in their hosts. As a result, *Wolbachia* may be used to study these basic processes.
- Third, there is widespread interest in using *Wolbachia* in biological control as a microbial “natural enemy,” to enhance productivity of natural enemies or as a vector for spreading desirable genetic modifications in insect populations.

## 4.20 Population growth curves

When the number of the individuals of the species plotted on the y-axis and time on the x-axis a curve is obtained that indicates the trend in the growth of the population size in the given area. Therefore the obtained curve of the population through the time is known as the population curve. There are two types of the curve

- a. S-Shaped curve or Logistic curve or Sigmoid curve
- b. J-shaped curve or Geometric curve

### a. S-shaped growth curve

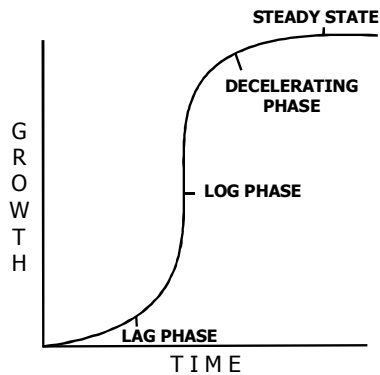
In the S-shaped curve the initial growth is slow and is known as lag and then occurs the positive acceleration phase. This is followed by the rapid growth continuous up to certain point after which there is the steady decrease in the growth taken as negative form. The level in which no major occurs occur is known as saturation level or the carrying capacity. The saturation point shows that there is the almost equal number of organisms taking birth and dying so that the equilibrium is established between natality and the environment resistance and maintaining a maximum number of the population density for the longer period. The curve results from the sigmoid form.

The sigmoid curve of the growth rate is common in population ecology. The S-shaped growth curve can be represented by:

$$\frac{dN}{dt} = r \cdot N \frac{(K-N)}{K}$$

where,  $\frac{dN}{dt}$  = Rate of population growth per unit time; N = Starting population; K = Maximum population size (constant) or carrying capacity of the environment;

$r$  = Rate of increase (intrinsic rate of increase)



#### b. J-shaped growth curve

The J-shaped growth curve involves the geometric ratio of the increase up to a certain point after which there is a sudden growth in the population. The change in the environmental factors makes the sudden change in the population. The more increase in the population also causes the decline in the food materials and also the habitat that alternately results in the decrease in the population size. The growth curve obtained in this progression is more or less J-shaped. This type of growth is not common in nature but found when the favourable condition meets the individual species needs.

The growth is given by the equation

$$\frac{dN}{dt} = r \cdot N$$

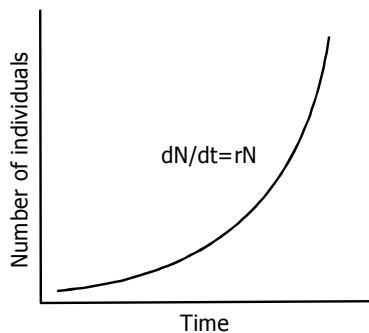
where,  $dN$  = Rate of the population growth;  $dt$  = Time interval;  $r$  = Rate of geometric change;  $N$  = population size

The integral population is

$$N_t = N_0 \cdot e^{r \cdot t}$$

This equation is widely used for the calculating growth

Where,  $N_t$  = number of the individuals at time  $t$ ;  $r$  = intrinsic rate;  $t$  = time taken



### 1. Opportunistic or The r - selected species

Every individual has the maximum reproducing capacity and has a characteristics mode of reproduction. At the one extreme, one species reproduce early and put most of their energy into the reproduction. they have many offspring's each time they reproduced, reach reproductive age rapidly, have short generation time, give their offspring's little or no time for the parental care or the protection to help them to the survival, short lived with a lifespan of less than a year.

The species with such a capacity for the higher intrinsic rate of increase ( $r$ ) are called r - selected species. E.g.; algae, bacteria, rodents, annual plants such as dandelion and most of the insects.

These species tend to be opportunistic and they reproduce rapidly under the favourable condition, even in the disturbed environment but the competition among the opportunists makes more or less unfavourable condition. Therefore mostly r - selected species go through the irregular unstable boom cycles of the growth in their population growth. To survive opportunists must continually invade new areas to compensate for being displaced by the more competitive species.

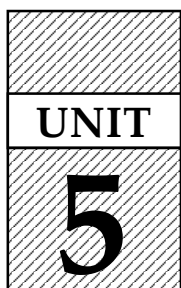
### 2. Competitive or K - related species

These species put fairly little energy in the reproduction, tend to produce late in the life, have a few offsprings with the long generation time, are cared for or protected by one or both the parents until they reach the reproductive age.

The result creates little individual competition for the resources and reproduces a few young to begin the cycle again. Such species are called k- selected species because they tend to do well in the competitive condition when their population size is near the carrying capacity of the environment. These follow logistic population growth. Examples are: Most large mammals such as elephant, whale, human etc. Birds, prey animal etc. Large plant such as oak trees, cactus, redwood trees and most of the tropical forest.

The k - selected species with the long generation time posses the low reproductive rate such as elephant, rhinoceros, shark etc. So in the general practice the k - selected species forms the best eco-system in the agriculture. The r-selected species experienced the habitat, forest, grassland and the raising crop.





# Biological Control

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## 5.1 HISTORY OF BIOLOGICAL CONTROL

- In 900 A.D. Chinese citrus growers used red ant, *Oecophylla smaragdina* on mandarin trees to control leaf chewing insects. This was the first use of insect predators
- In 1602, an Italian, Aldrovandi noted the hymenopteran parasite, *Apanteles glomeratus* laying eggs in the pupae of the cabbage butterfly, *Pieris brassicae*
- In 1762, Indian mynah bird, *Gracula religiosa* was exported from India to Mauritius to control red locust, *Nomadacris septemfasciata*
- In 1888, vadalia beetle, *Rodolia cardinalis* was brought from Australia and introduced into California (USA) to control cottony cushion scale, *Icerya purchasi* on citrus
- In 1898, coccinellid lady bird beetle, *Cryptolaemus montrouzieri* was introduced into India from Australia for the control of coffee green scale, *Coccus viridis*
- In 1929, vadalia beetle, *Rodalia cardinalis* was introduced into India (Tamil Nadu) for control cottony cushion scale, *Icerya purchasi*
- In 1937, *Aphelinus mali* was introduced from North America into Tamil Nadu for control of apple wooly aphid, *Eriosoma lanigerum*
- In 1960, a tachnid, *Spogossia bezziana* was introduced into India from Srilanka for the control of coconut black headed caterpillar, *Opisina arenosella*

## 5.2 BIO - CONTROL AGENTS

The different bio - control agents are

1. Predators
2. Parasitoids
3. Insect pathogens

## 1. Predators

Predators are free living and require several preys to complete the life cycle. They tend to feed on preys smaller than themselves.

Ex : Coccinellid beetles, ground beetles, anthocorid bugs, syrphid flies, and predatory mites

Coccinellid beetles are commonly called as ladybirds. These are hemispherical in shape and brightly coloured bearing distinct spots and stripes. These feed on aphids, scale insects, mealybugs and mites. Both grubs and adults are voracious feeders.

Vadalia beetle, *Rodolia cardinalis* is used for the control of cottony cushion scale on citrus. Australian lady bird beetle, *Cryptolaemus montrouzieri* is commonly used for the management of mealybugs and scale insects.

Coccinellids, *Pharoscymnus horni* and *Chilocorus nigrita* and *Stichlotis madagassa* are used in sugarcane for the control of scale insect, *Melanaspis glomerata*. Lady bird beetle, *Curinus coeruleus* is used for the control of psyllid, *Heteropsylla cubana* on subabul plantations.

*Chrysoperla carnea* and *Mallada boninensis* are used in cotton and citrus ecosystem for protection from aphids and other soft bodied insects. *C. carnea* feed on aphids, red mites, thrips, white and black flies, eggs of leaf hoppers, moths, leaf miners and small caterpillars.

Anthocorid bugs are used in sunflower for the management of thrips, aphids, eggs and young larvae of moths. Syrphid or hover flies are important predators of aphids of several crops. Syrphid, *Ischiodon scutellaris* is used in large scale in mustard and other crops. *Cryptorhinus lividipennis* is the most promising predator for the control of brown plant hopper, *Nilaparvata lugens* in paddy.

Predatory mites, *Phytoseiulus* spp. and *Amblyseius* spp. are important in controlling phytophagous mites in several crop ecosystems.

## 2. Parasitoids

Each parasitoid requires only one host, which it kills for its development into a free living adult. Parasitoids are of the same size as the hosts, or sometimes even smaller. The adult food of parasitoids is different from that of larvae. Many adult parasitoids feed on nectar or pollen.

Parasitoids may be specific or polyphagous. The host specific parasitoids are generally preferred for classical biological control for the management of introduced pests.

### Parasitoids are of different types

- a) **Egg parasitoids** : *Trichogramma* egg parasitoids are used for the management of tissue borers in sugarcane, stem borer in rice, boll worms in cotton and



pests of several crops. *Trichogramma chilonis* is used for the control of bollworms in cotton, internodal borer in sugarcane and rice leaf folder.

*Trichogramma japonicum* is used for the control of rice stem borer.

*Telenomus remus* is used for the control of tobacco caterpillar.

- b) **Egg larval parasitoids** : *Chelonus balckburni* is used for the control of spotted boll worm.

- c) **Larval parasitoids** : *Campolestis chloridae* is used for the control of *Helicoverpa armigera*

*Bracon hebetor* and *Bracon brevicornis* for the control of coconut black headed caterpillar.

*Platygaster oryzae* is used for the control of rice gall midge.

- d) **Larval pupal parasitoids** : *Isotima javensis* is used for the control of top shoot borer of sugarcane.

- e) **Pupal parasitoids** : *Trichospilus pupivora*, and *Brachymeria nephandidis* are used for the control of coconut black headed caterpillar.

- f) **Nymphal and adult parasitoids** : *Aphelinus mali* is used for the control of apple woolly aphid.

*Encarsia formosa* for the control of whitefly.

- g) **Ecto - parasitoid** : Ecto - parasitoid, *Epiricania melanoleuca* is used for the control of *Pyrilla perpusilla* on sugarcane.

### 3. Entomopathogens

Entomopathogens are disease causing organisms such as bacteria, viruses, fungi and protozoa in insect pest, which kill their host or debilitate the future generations. The infected insects are unable to feed properly, remain stunted, lose their body colour and gets immobile or paralyzed. Under certain conditions they cause disease epizootics in the field.

The various entomopathogens are

- |                                     |                  |
|-------------------------------------|------------------|
| a) Entomopathogenic bacteria        | b) Baculoviruses |
| c) Entomo - fungi                   | d) Protozoans    |
| e) Entomopathogenic nematodes (EPN) |                  |

#### a) Entomopathogenic bacteria

They are extra cellular associated with insects and enter the body cavity through contaminated feed and multiply. Death of the insect may be either due to intoxication, sudden lack of oxygen, chemical changes in the gut or by the toxins or crystals produced in the bacterial cells. Several commercial products

based on *Bacillus thuringiensis* and its sub sp. are available and are widely used for controlling lepidopteran pests. *B. thuringiensis* is recommended for the suppression of *Helicoverpa armigera* on tobacco, sunflower and pulses; *Achaea janata* on castor; *Spodoptera litura* on tobacco and beet root and *Adisura atkinsoni* on field beans.

*Bacillus thuringiensis* var. *kurstaki* against Lepidoptera.

*Bacillus thuringiensis* var. *galleriae* against wax moth.

*Bacillus thuringiensis* var. *sandiego* and *Bacillus thuringiensis* var. *tenebrionis* against beetles and weevils.

*Paenibacillus popilliae* is used against several species of white grubs including *Holotrichia consaguinea* and *Leucopholis coneophora* on groundnut and *L. lepidophora* on sugarcane.

#### b) Baculoviruses

Viruses are submicroscopic, obligate, intracellular pathogenic entities. Viruses in the family of baculoviridae are the best known of all the insect viruses because the disease symptoms are easily recognized and they have potential for the development as microbial insecticides. Baculoviruses are double stranded DNA viruses having baciliform or rod shaped virions. Important sub groups within the family are Nuclear Polyhedrosis Viruses (NPV) and the Granulosis Viruses (GV) which are widely used in pest control. The NPVs are specific to host species or genus. GVs are more specific than the NPVs and are reported from Lepidoptera. Commercial formulation of NPVs are commonly used by the farmers for the management of tobacco caterpillar and gram caterpillar. Addition of optical brighteners, tannic acid, boric acid, jaggery improves the effectiveness of NPVs.

NPV of *Amsacta albistriga* and *A. moorei* are used on groundnut for the control of red hairy caterpillars. *Ha-NPV* is used for the control of *Helicoverpa armigera* on cotton, chickpea and groundnut. *Sl-NPV* is used for the control of *Spodoptera litura* on tobacco, groundnut, black gram and cotton.

GV of *Chilo infuscutellus* is used for the management of shoot borer on sugarcane

#### c) Entomofungi

Different entomofungal pathogens such as white muscardine, green muscardine and yellow muscardine are known to attack various pests. The spores of the fungus directly penetrate integument of pest and body cavity is attacked. The fungus with its mycelium and spores cover the body of host.

*Beauveria bassiana* against rice hispa, *Spodoptera litura* and lepidopteran tissue borers of sugarcane. *Metarrhizium anisopliae* and *Beauveria brongniartii* against *Holotrichia serrata* and *Leucopholis lepidophora* on sugarcane and

*Holotrichia consanguinea* on groundnut and on *Oryctes rhinoceros*. *Nomuraea rileyi* against *Spodoptera litura*; *Fusarium oxysporum* on *Nilaparvata lugens*, *Verticillium lecanii* on *Coccus viridis* and *Hirsutella thompsoni* on mites

**d) Protozoans**

Protozoa kill the insects either directly or by reducing the fecundity of the adult. Their effect on host is chronic. They prolong the larval life in the field, thus exposing the insect longer to predators and parasitoids. These are called debilitating infections. They are always associated with other pathogens

Ex: *Nosema melolonthae* against chaffer beetles

*Farinocystis triboli* against red flour beetle

*Nosema locustae* against grasshoppers

**e) Entomopathogenic nematodes (EPN)**

Entomopathogenic nematodes (EPN) (Steinernematids and Heterorhabditis) directly attack the insect pests. The invasive larvae of EPNs carry the associated bacteria *Xenorhabdus* sp. or *Photorhabdus* sp. in their gut, which not only kill the invaded host within 24-48 hr but also produce a biostatic substance that retards the putrefaction of the cadaver. The nematodes feed on these bacteria and are capable of producing several generations in their dead hosts. The EPNs are susceptible to desiccation.

Ex: *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* against soil inhabiting insects and tissue borers.

### 5.3 ENTOMOPHAGOUS INSECT ORDERS AND FAMILIES

Entomophagous insect orders and families containing

- |                |               |
|----------------|---------------|
| I. Parasitoids | II. Predators |
|----------------|---------------|

**I. Entomophagous insect orders and families containing parasitoids**

The important entomophagous insect orders are

- |                |                 |
|----------------|-----------------|
| a. Hymenoptera | b. Strepsiptera |
|----------------|-----------------|

**a. Hymenoptera**

**1. Ichneumonidae (Ichneumon flies)**

- These are important parasitoids of larvae and pupae of Coleoptera, Hymenoptera and Lepidoptera

- Antennae is long with typically 16 or more segments
- Ovipositor is long and extruded permanently
- Long antennae, presence of trochantellus on hind femur
- Absence of anal lobe on hindwing
- Distinct pterostigma and narrow costal cell on forewing
- Two distinct recurrent cross veins

Ex : *Isotima javensis*

## 2. Braconidae (Braconids)

- Most braconids are primary parasitoids (both external and internal) on other insects
- Very small stout bodied insects
- Ovipositor is long and many species are egg - larval parasitoids
- Only one recurrent vein, cross vein 2m- Cu is absent in the fore wing
- Pupation with in cocoon inside or outside the body of host

Ex : *Bracon hebetor*

## 3. Evaniidae (Ensign wasps)

- These are small black insects
- They carry the gaster almost like a flag and hence the common name Ensign wasps
- Antennae inserted well above the clypeus
- Long and abrupt petiole
- Compressed and short gaster
- Short ovipositor
- They are parasite on ootheca of cockroaches

Ex : *Evania appendigaster*

## 4. Aphelinidae

- These are small to minute size (1 mm or less) insects
- These are mostly yellow sometimes black
- Tarsi 5 segmented
- Antennae with 8 or less segments
- Mostly parasitic on aphids, coccids and whiteflies

Ex : *Aphytis diaspidis*

**5. Scelionidae**

- These are small insects
- These parasitize the eggs of Lepidoptera, Orthoptera, Dictyoptera, Hemiptera etc.
- The phenomenon of phoresy is observed  
Ex : *Telenomus beneficiens*

**6. Pteromalidae**

- These are minute brightly coloured insects
- Thorax short and small sub triangular gaster
- The fused 2<sup>nd</sup> and 3<sup>rd</sup> tergites cover most of the gaster
- Adult female feeds on the body fluid of the host  
Ex : *Cardiogaster barodensis*

**7. Platygasteridae**

- Small minute black insects
- Antennae 10 segmented, clubbed, or geniculate
- Fore tibia with single spur
- Wings with out venation, with long marginal fringe
- Ovipositor extremely long
- These are parasitic on whiteflies and cecidomyiid flies  
Ex : *Platygaster oryzae*

**8. Chalcididae (Chalcid wasps)**

- Minute to small metallic coloured insects
- Primary or secondary parasites of eggs, larvae and pupae of insects
- Hind femur stout and swollen with rows of short teeth (characteristic feature)
- Wings are not folded longitudinally at rest
- Ovipositor short and straight  
Ex : *Brachymeria* sp.

**9. Encyrtidae**

- These are small parasitic wasps
- The cerci forwards on the metasoma
- Greatly enlarged mesopleuron with anteriorly-positioned mesocoxae
- Some species exhibit polyembryony

- These insects are parasite of aphids, whiteflies and scales insects

Ex: *Anicetus communis*

#### 10. Trichogrammatidae

- These are very minute insects with three segmented tarsi
- Fore wings are broad with rows of microscopic hairs
- These parasitize the eggs of large number of insects especially Lepidoptera
- They are not strong fliers and passive fliers (move along with the wind)
- Forewings are stubby and paddle-shaped, with a long fringe of hinged setae around the outer margin to increase the surface area during the downstroke

Ex: *Trichogramma chilonis*

#### 11. Bethyilidae

- Small to medium-sized wasps, dark coloured with an elongate head
- These are parasitic on larvae of Lepidoptera and Coleoptera
- Slightly elbowed, 12 or 13 segmented antennae
- The wing venation is reduced, and the hind wing has a jugal lobe
- The females of many species are apterous and ant-like, and a few will sting
- The larvae are external parasites, pupates in a silken cocoon

Ex: *Nephantis serinopa*

#### b. Strepsiptera

##### 1. Myrmecolacidae

- Seven segmented antennae
- Tarsi with less than 5 segments
- Claws absent
- In females the cephalothorax with hood
- Scutellum shorter than prescutum
- These are parasites of males of Formicidae and females of Orthoptera

Ex: *Myrmecolax*

##### 2. Stylopidae

- Four to 6 segmented antennae and third segment is laterally flabellate
- The cephalothorax in females is with one pair of spiracles
- Genital tubes 2 - 5
- These are parasites of sting bearing Hymenoptera

Ex: *Stylops* and *Parastylops*

### 3. Halictophagidae

- Males possess 7 segmented antennae
- Tarsi 3 segmented
- Brood passage openings is narrow, linear or oblong in females
- These are parasites of Homoptera

Ex : *Halictophagus*, *Tettigoxenos*

## II. Entomophagous insect orders and families containing predators

The important entomophagous insect orders are

- |                |                |               |               |
|----------------|----------------|---------------|---------------|
| a. Odonata     | b. Dictyoptera | c. Hemiptera  | d. Coleoptera |
| e. Hymenoptera | f. Lepidoptera | g. Neuroptera | h. Diptera    |

### a. Odonata (Dragonflies and damsonflies)

- Large sized insects, nymphs are aquatic and adults are terrestrial
- Immature stages are called niads and feed on aquatic insects
- Labium is modified into a prehensile organ called mask for catching prey
- Nymphs with rectal gills for respiration
- Adults are active fliers
- Secondary copulatory apparatus on 2<sup>nd</sup> and 3<sup>rd</sup> sterna
- Adult are capable of catching prey during flight with the help of basket shaped legs

Ex : *Nepogomphus*, *Cordulegaster*

### b. Dictyoptera

#### 1. Family Mantidae

- Pronotum does not cover the head
- Ocelli 3 in number and well developed
- Forelegs are raptorial
- Proventriculus is not armed with teeth
- Carnivorous, feeds on flies, caterpillars, grasshoppers etc.

Ex : European mantis (*Mantis religiosa*) and *Gongylus gongyloides*

### c. Hemiptera

#### 1. Reduviidae (Assassin bugs)

- Brown to black, medium sized insects

- Rostrum 3 segmented, curved and its tip fits in a posterior groove
  - Fore legs bear adhesive pads on tibia
  - Metathoracic scent glands absent
  - Most of these are predaceous and some are blood sucking
- Ex : *Harpactor costalis*

**2. Gerridae (Pond skaters or water striders)**

- Head is elongated and slender with 4 segmented rostrum
  - Fore legs are short for capturing the prey
  - Middle and hind legs are used for locomotion
  - Tarsi 2 segmented with fine hairs
  - These are predaceous bugs which live on the surface of water
- Ex : *Gerris tristan*

**3. Anthocoridae (Flower bugs)**

- Small insects with elongate to oval body
  - Three segmented rostrum
  - Tarsi 3 segmented
  - Scent gland on metathorax
  - These are predaceous on mealy bugs, mites and thrips
- Ex : *Orius indicus*

**4. Miridae (Leaf or plant bugs)**

- These are delicate small to medium sized elongated insects
  - Antennae and rostrum are 3 segmented
  - Ocelli absent
  - Tarsi 3 segmented
  - Distinct cuneus and an indistinct embolium
  - Ovipositor well developed in females
- Ex : *Psallus* spp.

**5. Lygaeidae (Chinch bugs)**

- Small, brightly coloured with red, black or white spots or bands
- Both antennae and rostrum 4 segmented
- Legs possess rotatory coxae and tarsi 3 segmented
- Wings are characterized by 4 or 5 simple veins in the membrane of the hemelytra



- Some are predaceous on aphids

Ex: *Geocoris tricolor*

#### 6. Pentatomidae (Stink bugs)

- Brightly coloured, medium size and shield like shape, produce disagreeable odour
- Antennae 4 or 5 segmented and base is concealed by lateral margin of the head
- Scutellum triangular and extends posterior and covers the wings entirely
- Hemelytra well developed with 5-12 veins
- Mostly phytophagous and some are predaceous

Ex: *Cantheconia* sp.

### d. Coleoptera

#### 1. Coccinellidae (Lady bird beetles)

- Adults are small, oval or spherical, convex, brightly covered with coloured spots
- Head concealed in pronotum
- Tarsi 4 segmented and 3<sup>rd</sup> segment concealed in the deeply bilobed second segment
- Antennae short, clubbed 3 to 6 segmented
- Larvae campodeiform usually covered with minute tubercles or spines
- Both adults and grubs are predaceous on soft bodied insects and mites

Ex: *Coccinella septempunctata*

#### 2. Carabidae (Ground beetles)

- They live under stones, ground and bark
- Oval and broad, dorsoventrally flattened beetles with metallic, bright dark coloration
- The elytra are firmly attached together and wings may be atrophied
- The legs are slender and adapted well for running and digging
- Adults and larvae are carnivorous, most of them feed on caterpillars

Ex: *Anthia sexguttata*

#### 3. Meloidae (Blister beetles)

- Medium sized insects
- Elytra are brightly coloured with transverse coloured strips

- Head hypognathous, strongly deflexed
- Legs long with tarsal claw
- Tarsi 5 segmented
- Adults on disturbance emit a defensive oily fluid containing canthardine
- Hyper metamorphosis is common
- The grubs are predaceous on eggs of grasshoppers

Ex : *Mylabris pustulata*

**4. Cantharidae (Soldier beetles)**

- Elongate yellowish, black or brown beetles
- Males are winged, females are apterous
- Fourth tarsal segment with a bilobed ventral lobe
- Larvae with flat head, short antennae and a single ocellus
- These feed on mealy bugs, aphids and small insects

Ex : *Cantheris* sp.

**5. Cicindelidae (Tiger beetles)**

- Large 10 - 25 mm long beetles
- Eyes large and prominent
- Mandibles large and acutely toothed
- Legs are long adapted for running
- Larvae with six ocelli (2 vestigial) on either side
- A pair of hooks on the 5<sup>th</sup> abdominal segment
- Both adults and grubs are predaceous
- Adult are active and capture prey with sickle shaped mandibles

Ex : *Cicindela cancellata*

**6. Staphylinidae (Rove beetles)**

- Small to medium sized insects
- Short elytra considerable portion of abdomen is exposed
- The mandibles are well developed and cross in front of the head
- The well developed hind wings are kept folded under the elytra at rest
- Predaceous on saprophagous insects

Ex : *Paederus fuscipes*

**e. Hymenoptera**

**1. Sphecidae**

- Pronotum terminating laterally in a rounded lobe that does not reach the tegula
- They sting and paralyze caterpillars, bugs, Orthopterans and Archnida
- Many nest in pre-existing cavities or dig simple burrows in the soil

Ex : *Ammophila sabulosa*

**2. Vespidae (Social wasps)**

- Red or yellow body with black markings
- Antennae 12 segments in females and 13 segments in males
- Long slender petiole and forewings possess a very long first dicoid cell
- Sub marginal cells 3 in forewing, hindwings with out anal lobe
- Trochanter undivided and no trochantellus
- Abdomen is sessile and modified into terminal ovipositor or sting

Ex : *Vespa cincta*

**f. Lepidoptera**

**1. Heliodinidae**

- Small moths with slender bodies
- Narrow lanceolate fringed hindwings
- The hindlegs are elevated above the wings at rest
- These are predaceous on coccids

Ex : *Stathmopoda*

**2. Lycaenidae**

- Adults are small and brightly coloured, sometimes with a metallic gloss
- The male's forelegs are reduced in size and lack claws
- Tail like delicate prolongations are seen on the hindwings
- Larvae are often flattened rather than cylindrical, with glands that produce secretions that attract and subdue ants
- Some larvae are predaceous on aphids and coccids

Ex : *Spalgius epius*

### 3. Noctuidae

- Moths are cryptic and dull coloured
- Insects are nocturnal and attracted to light
- Proboscis is present and labial palp is long and well developed
- Maxillary palpi minute
- $Cu_2$  absent in both wings
- Larvae with all prolegs bearing crochets except in semiloopers in which first two pairs are wanting
- Some larvae are predaceous on larvae of coccids (lac insect)

Ex : *Eublemma amabilis*

### 4. Epipyropidae

- Small moths
- Larvae are ectoparasites, the hosts typically being fulgoroid planthoppers
- Also called as planthopper parasite moths

Ex : *Epiricania melanoleuca*

### g. Neuroptera

#### 1. Sialidae (Alder flies)

- Body length less than 25 mm (1 inch)
- Long filamentous antennae
- Anterior pair of wings is slightly longer than the posterior
- Ocelli absent
- Fourth tarsal segment is dilated and deeply bilobed
- Larvae aquatic with 7 pair of gills
- Larvae are predaceous on mayflies, stoneflies and dragonflies

Ex : *Sialis lutaria*

#### 2. Coniopterygidae

- Antennae long and filiform
- Fragile wings covered with a white waxy powder
- These are predaceous on coccids, aleyrodids, aphids and mites

Ex : *Coniapteryx pusanus*

### 3. Mantispidae

- Prothorax elongate
- Short antennae, large eyes
- Raptorial legs
- They feed on eggs and cocoons of spiders

Ex : *Mantispa*

### 4. Chrysopidae (Aphid lions)

- Bright green body with wing veins and iridescent eyes
- Antennae filiform
- $R_3$  arising from main separating from  $R_1$  and does not fuse distally with Sc
- Eggs with long pedicel
- They commonly feed on aphids, thrips, psyllids, coccids, jassids etc.

Ex : *Chrysoperla carnae*

### 5. Myrmeleontidae (Ant lions)

- Adults with long, narrow, many veined clear or spotted wings, no pterostigma
- Abdomen long and slender
- Body soft and antennae clubbed
- Larvae are called ant lions as they feed on ants

Ex : *Myrmeleon formicarius*

## h. Diptera

### 1. Asilidae (Robber flies)

- Long bristle flies with horny piercing proboscis
- Strong prehensile fore legs for catching and peircing the prey
- Tuft of hairs forming bearded face and protruding eyes (characteristic feature)
- The legs end in a bristle like empodium and large pulvilli
- Larvae are cylindrical with small conical head
- Pupa with girdles of spines dorsally on head and trunk
- Larvae are predaceous on grasshoppers, beetles, wasps etc.

Ex : *Allocotosia aurata*

### 2. Syrphidae (Hover flies)

- Adults are often seen hovering or nectaring at flowers, hence called hover flies

- Wasp or bees like, brightly coloured with yellow stripes or bands
- Larvae are insectivorous and prey on aphids, thrips, and other plant-sucking insects
- Hover flies are distinguished from other flies by a spurious vein, located parallel to the fourth longitudinal wing vein

Ex : *Syrphus confractor*

### 3. Tachinidae (Tachnid flies)

- These are stout flies, medium to large, that are very bristly, particularly around the posterior of the abdomen
- Adults with pteropleural and hypopleural bristles
- Abdomen clothed with long conspicuous marginal, apical and dorsal bristles
- The larvae are internal parasitoids of insects especially Lepidoptera and adults feed on nectar
- Pupates outside the body of the host

Ex : *Sturmiopsis inferens*

## 5.4 ASPECTS OF BIOLOGICAL CONTROL

■ The different aspects of biological control are

1. Ecological aspects
2. Biological aspects
3. Taxonomic aspects
4. Economic aspects
5. Legal aspects

### 1. Ecological aspects

This deals with the changes in insect populations.

Insect populations have two attributes, homeostasis and regulation. Homeostasis refers to the stability of population over along range of time and regulation is the dynamic equilibrium of population brought about by parasites and predators.

The dynamic equilibrium is altered by an accidental transfer or migration of resident species to a new area. Because of the absence of natural enemies in the new area the insect will flourish and pose a pest problem. Biological control attempts to provide the missing natural enemies by transporting them from their native homes to the new homes of the pests.

## 2. Biological aspects

This deals with the classification, nutrition, behavior, mating and oviposition of the entomophagous insects.

- **Classification** : The entomophagous insects are classified into parasitoids and predators. The parasitoids may be external, internal, solitary or gregarious. These can parasitize any stage of their host and therefore could be egg, larval, pupal and adult parasitoids.
- **Nutrition** : The distribution of parasites and predators depend on the presence of food sources. Protein is required by the female for fecundity therefore flowering plants should be provided in the habitats of the parasites.
- **Behaviour** : It refers to the manner in which the parasites and predators find their host. Host odour, shape, size, physiological condition and contact provide necessary stimulus to attack. Four steps are involved in which parasites and predators search for their hosts. They are, host habit finding, host finding, host acceptance and host suitability.
- **Mating and oviposition** : Mating habits differ among different insects or between two sexes of the same insects. Some insects may be polygamous and others may be monogamous. Oviposition may be done away from the host, or on the host or inside the host.

## 3. Taxonomic aspects

The correct identification of the pest is most crucial in the search for its natural enemy. In case the pest is having sibling species, these sibling species should be correctly identified for effective control.

## 4. Economic aspects

Biological control method is economical in the long run in spite of the substantial initial investment because if successful it is self sustaining and does not need repeated applications like the conventional chemical methods.

## 5. Legal aspects

Import of parasites and predators from a particular country and their introductions into the ecosystem of another country to be taken up by legislative laws called quarantine regulations. These restrict the movement of organisms from one place to another, provide terminal inspection of organism at the port of entry and enforce observations of imported organisms in quarantine laboratories.

## 5.5 TYPES OF PARASITISM

### ■ Types of parasitism

- |                             |                     |
|-----------------------------|---------------------|
| 1. Simple parasitism        | 2. Hyper parasitism |
| 3. Multiple parasitism      | 4. Super parasitism |
| 5. Clepto parasitism        | 6. Auto parasitism  |
| 7. Polyembryonic parasitism |                     |

#### 1. Simple parasitism

A single attack of the parasitoid on the host irrespective of the number of eggs laid is called simple parasitism.

Ex: *Goniozus nephantidis* on the larvae of coconut black headed caterpillar

#### 2. Hyper parasitism

A parasitoid which attacks another parasitoid. It is the parasitism of a parasite. The hyper parasite is in fact as secondary parasite. These reduce the efficiency of the primary parasite.

Example :

- i). The moth *Hyphantria* (primary host) is primarily parasitized by the dipteran-tachnid larvae, *Ernestia* (primary parasitoid) and it is, thereafter parasitized by the chalcid larvae, *Perilampus*, which is a hyper parasitoid.
- ii). Aphid is primarily parasitized by the ichneumon, *Aphidius* (primary parasite) and it is later on, parasitized by the cynip gall fly, *Charips* or chalcid, *Asaphes* fly, which are hyper parasitoids.
- iii). *Aphanogmus fijiensis* is a hyper parasitoid on cocoons of *Cotesia flavipes*, a primary parasitoid of *Chilo partellus*.
- iv). The cabbage butterfly larvae *Pieris* (primary host) is parasitized first by hymenopteran *Apanteles glomeratus* (primary parasite) and it thereafter, parasitized by another hymenopteran- *Natrastacus rape* which is a hyper parasitoid.

#### 3. Multiple parasitism

Parasitism by different species of parasitoids on the same host at a time is called multiple parasitism.

Example :

- i). *Bracon brevicornis*, *Eriborus trochanteratus* and *Goniozus nephantidis* attack



larvae of black headed caterpillar at the same time.

- ii). Chalcids, *Eurytoma monemae* and *Chrysis shanghaiensis* attack the fully grown caterpillar *Monema flavescens* at the same time.
- iii). Fruit fly, *Dacus cucurbitae* larvae is parasitized first by the braconid, *Opius flatcheri* larvae and later on by the 2<sup>nd</sup> parasite chalcid, *Tetrastichus giffardianus*
- iv). Parasitization of a lepidopteran eggs by two primary parasitoids, *Trichogramma* spp. and *Telenomus* spp. at the same time.

#### 4. Super parasitism

Many individuals of the same species of parasitoid attack a single host at a time is called super parasitism.

Example :

- i). *Trichospilus pupivora* on the pupae of black headed caterpillar
- ii). Aphid parasitized by the braconid, *Aphidius* larvae
- iii). Caterpillar *Artona* is parasitized by the larvae of chalcid, *Elachertus*

#### 5. Clepto parasitism

A type of parasitism in which the adult parasitoid preferentially appropriates for its own progeny the previously paralyzed and parasitized host of another parasitoid.

Example : Pine shoot moth attacked by either *Eurytoma pini* or *Rhyacionia buoliana* one followed by another

#### 6. Auto parasitism

It is also called as Adelpho parasitism. A special type of parasitism in which the female develops as a primary parasitoid, but the male is a secondary parasitoid through females of its own species.

Example :

- i). Males of *Coccophagoides utilis* develop as hyper parasite from unfertilized egg laid by parent female of *C. utilis* a primary parasitoid of purple citrus scale, *Parlatoria oleae*.
- ii). Chalcidoid, *Encarisa formosa* females develop on the whitefly while males become internal hyper parasites of the larvae females of their own species

#### 7. Polyembryonic parasitism

It is the phenomenon of an individual host by single larvae of a single parasitic species, but develops into several parasitoids within the host body

Example : Potato tuber moth attacked by *Copidosoma koehleri*

## 5.6 PRINCIPLES AND PROCEDURES OF BIOLOGICAL CONTROL

■ Principles and procedures of biological control include 4 steps. They are

- |                                    |                 |
|------------------------------------|-----------------|
| 1. Introduction of natural enemies | 2. Colonization |
| 3. Augmentation                    | 4. Conservation |

### 1. Introduction of natural enemies

The following ecological points to be considered for successful natural enemy introduction

- The natural enemy should be imported from a place having similar climate
- It should be free from alternate hosts
- It should be free from hyper parasitoids and other biological competitors for the hosts
- Physiological suitability of the natural enemy to its host and suitability of the host plant ecosystem
- Imported natural enemy should have low dispersal

### 2. Colonization

Mechanism for manipulation an organism to establish it in a new locality is called colonization.

Colonization is most critical operation in biological control and to make it successful the following considerations are made

- The site chosen for colonization should be thoroughly protected from pesticides and cultural practices
- The natural enemy should be stored at low temperature (16°C) to curtail activity
- Adult stage in most of the parasitoids and predators is considered appropriate than immature stages because adults can easily cope up with the new environment and are less affected by the biotic and abiotic stresses
- Natural enemies should be released in the field in the vicinity of a suitable host
- Natural enemies should be transported in container with suitable relative humidity
- In order to avoid direct heat they may be released either early in the morning or in the late evening
- Natural enemies about to be released should be fed and mated before release
- The number released should depend up on the natural enemy's host searching ability

Recovery attempts are undertaken soon after the initial release to ascertain if the released natural enemies are surviving and control is being provided.

### **Evaluation of natural enemies**

A minimum period of 3 years is given before assessing the results

Evaluation of the effectiveness of the natural enemy is done by

- Comparing the host population of the pest before and after the release
- Correlating population changes of the natural enemy and the host
- Comparing the population on plots with and with out the natural enemy

They are two important systems that are normally followed for evaluating the effectiveness of a natural enemy

- a). Experimental procedures (Natural enemy exclusion method)
- b). Analytical procedures (Use of life table analysis method)

In exclusion method, exclusion of natural enemy can be achieved by hand picking, chemical barrier of insecticides and use of ants

In analytical procedures, life and mortality and causes of mortality (life table) are determined in the light of various environmental factors for different stages. The data is analyzed to correlate between pest density and changes in density and the amount of mortality resulting from each measured mortality factor.

### **3. Augmentation**

It includes all activities designed to increase numbers or effect of existing natural enemies. These objectives may be achieved by releasing additional numbers of natural enemies into a system or modifying the environment in such a way as to promote greater numbers or effectiveness.

These releases differ from introduction in that these have to be repeated periodically.

The periodic releases may be

- i). Inoculative releases
- ii). Inundative releases

#### **i). Inoculative releases**

These may be made as infrequently as once in a year to reestablish natural enemy. Here control is expected from the progeny and subsequent generations and not from the release itself.

#### **ii). Inundative releases**

It involves mass culture and release of natural enemies to suppress the pest

population directly. These are effective against pests having one or a few discrete generations every year. Here the control is from release itself.

#### 4. Conservation

**Conservation of bio - control agents can be achieved by**

- a. Rationalizing use of pesticides
- b. Providing food and shelter
- c. Beneficial management practices
- d. Suppression of ants
- e. Determining the need for action
- f. Influence of plant types
- g. Trap cropping

##### a. Rationalizing use of pesticides

Pesticides affect the natural enemies by repelling or reducing the longevity, fecundity and searching ability and decimating the population of the flying adults.

These can be avoided by

- Use of non – persistent pesticides
- Skip row treatment with pesticides
- Use of safe and selective pesticides
- Use of minimum recommended dose
- Application during specific time in a limited area
- Use of microbial pesticides instead of synthetic pesticides

##### b. Providing food and shelter

- Nesting boxes and bird perches act suitable sites and encourages build up of predators
- Pollen and nectar bearing flowering plants are planted on the bunds to provide supplementary food to predators
- Natural enemies multiply in unsprayed niches hence the parasitoids could be released in such places to create reservoirs

##### c. Beneficial management practices

- Chisel ploughing conserve natural enemies of soil inhabiting pests
- Manipulation of relative humidity and wetting periods enhances the efficacy of entomo fungal pathogens

- Use of organic manures conserves predaceous arthropods and soil borne microbial antagonists of insect pests
- Several parasitoids could be conserved if crop residues are left unburned
- Parasitoids should be released at a time when the activity of hyper parasites is least
- Retention of crop stubble as well grass weed heaps helps to maintain predator population
- Keep a part of refuge in net mesh cages to allow emergence of parasitoids in the field
- Over wintering stages or eggs of parasitoids are to collected and kept in cages and parasitoids emerge from these cages are used early in the season

**d. Suppression of ants**

- Suppression of ants or their physical exclusion increase the efficiency of predators

**e. Determining the need for action**

- The time and period of natural enemy should synchronize with the availability of suitable stage of the pest
- The need of action has to be determined for each crop ecosystem, based on population of the natural enemies and their feeding or parasitizing potential
- When parasitoids are active predators should not be released similarly when entomo pathogens are active parasitoids should be released for effective control

**f. Influence of plant types**

- The plant leaf pubescence affects searching efficiency, parasitism, oviposition and prey consumption
- The colour of the leaf and flower bud plays a major role in attraction or repelling parasitoids
- Varieties with more flowers, good canopy and more nectaries increase the effectiveness of the entomo pathogens by providing shelter and food
- Morphological characteristics of the host plant and the differences in profile of volatile contents between the cultivars play an important role in the effectiveness of the predators and parasitoids

**g. Trap cropping**

- Growing of trap crops along with the main crop increase the overall efficiency of parasitoids and several predators

## 5.7 TECHNIQUES FOR EVALUATION OF NATURAL ENEMIES

The various techniques used for the evaluation of natural enemies are

- I. Qualitative method
- II. Quantitative method
- III. Life table technique
- IV. Experimental methods

### I. Qualitative method

This method is useful for newly introduced pests or pest of previously known history. It is done by comparing the rate of spread, damage done by the pest before and after the release or introduction. The inundative release effect is determined by comparing the damage of pest to that of previous years. This method is less precise compared to other methods.

### II. Quantitative method

In this method regular sampling is done to determine the precise effect of release in suppression of the target pest. The success on natural enemy released is indicated by a decrease in pest population during its active infestation period and increase in natural enemies' population.

#### Disadvantages

- Removal of field material while sampling
- Fluctuation of host and parasitoid population at each sampling
- Variability in duration of host stage due to parasitism
- Several separate attacks by a parasitoid on the same host
- Difference in the availability of hosts

### III. Life table technique

This method provides a tabular accounting of mortality and its causes for each insect stage during crop period. The data is correlated with changes in pest density and amount of mortality resulting from each measured mortality factor. Future population trend of the host and released natural enemy could be predicted by this method to make decisions.

### IV. Experimental methods

These methods are applied in the field for natural enemy exclusion to study the effectiveness of natural enemy. They are

- a. Mechanical barrier method
- b. Chemical exclusion method
- c. Biological check method
- d. Hand removal method
- e. Trap method

**a. Mechanical barrier method**

In this method a mechanical device such as cage, cloth sleeve or wire screen is used to enclose an uninfested plant and the pest is introduced into the this zone. This is compared to another plant (not enclosed in cage) or plots which is exposed to natural enemies. The density of pest population tends to increase in caged plots and the pest population remains low in uncaged plots. The difference in density is ascribed to the action of the excluded natural enemies. Limitations of this method is the variable environmental factors in different treatments.

**b. Chemical exclusion method**

In this method a selective pesticide is used to eliminate the natural enemy so the pest is unaffected by the natural enemy. Growth of the pest provides the natural enemy effectiveness. Then the population is compared with that of untreated plot.

**The advantages of this method over the mechanical methods are**

- Free host dispersal
- Option for selecting large plot size
- The microclimate is not modified

**c. Biological check method**

This method is used in symbiotic association between ants and homopterous insects. The ants are attracted to the honey dew secretion by the homopterous insects which in turn protect these insects from parasitoids and predators. The ants are restricted from the experimental plant there by exposing the pest population to full attack by natural enemies. This leads to decline in pest populations. Then finally the role of natural enemies in ant attended plots is compared to the plots without ants.

**d. Hand removal method**

In this method efforts are made to remove the natural enemies from experimental plant by hand. This produce a real difference between treated and untreated plots.

**e. Trap method**

In this method untreated central area is surrounded by a treated area where natural enemies that try to leave or enter the untreated area are killed. The effectiveness is determined by comparing the populations of host and natural enemy in untreated area with that of treated one.

**5.8 MASS MULTIPLICATION TECHNIQUES****I. Mass multiplication techniques of various parasitoids****1. Mass rearing of egg parasitoid, *Trichogramma* sp**

*Trichogramma* spp. commonly known as the wasp is an egg parasitoid of many lepidopteran insect pests. It is reared on the eggs of rice meal moth, *Corcyra cephalonica*. Fresh eggs of *Corcyra* are sterilized by exposing to UV light to kill the embryo. These eggs are glued to Trichocard in a uniformly thin layer. About 1 cc (18,000 – 22,000) eggs are glued to each Trichocard. The card is further divided into six strips and these are inserted into another glass tube having newly emerged adults of the *Trichogramma* sp. The adult parasitoids are fed with honey applied on the inner sides of the tube that is secured tightly with markin cloth and rubber bands. The card is changed after 24 hrs and replaced with fresh card. The cards are changed for 3 - 4 days or till the female survives and remains productive. The parasitoid female oviposit's in the host egg, which turns black after 3 days of parasitization. At this stage, the parasitized eggs can be used for field release or stored at 10°C for fortnight.

**2. Mass rearing of egg parasitoid, *Teloneus remus***

It is an egg parasitoid and it can be reared on *Spodoptera litura* eggs. The eggs of host insect are pasted on egg card and exposed to freshly emerged parasitoids for parasitization in glass vials. Honey in the form of fine lines is applied on the inner walls of the vials. The parasitized eggs will turn grayish black on the 7<sup>th</sup> day of parasitization and at this stage these can be used for field release.

**3. Mass rearing of larval parasitoids, *Bracon hebetor* and *B. brevicornis***

*Bracon* sp. is an external gregarious larval parasitoid. Fully grown larvae of *Corcyra cephalonica* is used as host for mass rearing. The broader end of the chimney is covered with muslin cloth. *Corcyra* larvae are placed on the muslin cloth and tightly covered with another muslin cloth by using a rubber band. The adult parasitoids soon after emergence are held in glass jar and fed with raisins. After mating,



two mated females of *Bracon* are released to each *Corcyra* larvae though the narrow end of the chimney which is covered with another muslin cloth. The female *Bracon* lays about 8-12 eggs on the ventral side of the caterpillars. After one day the parasitized larvae are removed gently with the help of forceps and kept on paper plates so to avoid falling of the eggs laid on the host body. The parasitized larvae are left undisturbed till cocoon formation. After cocoon formation the remnants of the dead larvae are removed. The cocoons are placed in a glass jar for emergence and adult are fed with raisins.

#### 4. Mass rearing of larval parasitoid, *Cotesia (Apanteles) flavipes*

The larval parasitoid, *Cotesia (Apanteles) flavipes* can be reared on the larvae of *Chilo partellus*. The parasitoid culture can be collected from parasitized larvae of *C. partellus* infecting sorghum. These larvae are either kept for development on splitted stems of sorghum or artificial diet. Cocoon mass from the carcasses of parasitized larvae are gently removed and kept in a tube for emergence. Newly emerged mated pair is separated, offered 10 larvae of *C. partellus* and covered with black paper leaving 2 - 3 cm bottom to restrict parasitoid activity in this zone. Host larvae are replaced every day with a set of another fresh larva till parasitoid remains alive and are reared on artificial diet / natural food till cocoon formation.

#### 5. Mass rearing of larval parasitoid, *Cotesia (Apanteles) angaleti*

It is an internal solitary larval parasitoid. It can be reared on larvae of *Corcyra cephalonica*. The rearing cage consists of two glass troughs of 15 × 10 cm size. One trough is filled with water up to 2 cm height and covered with a piece of nylon wire mesh held tightly by means of adhesive tape. A small Petri dish containing first instar larvae of *C. cephalonica* in thin film of flour is placed on the wire mesh. Every day series of Petri dishes are prepared with a layer of first instar larvae of about 3 mm height, sprinkled with fresh eggs of *C. cephalonica*. Fresh raisins are provided in another dish as food to the adult parasitoids. The other trough is inverted over the newly emerged parasitoids. About 2 cm layer of water is poured in the lower trough to increase the ideal humidity in the upper chamber and to enhance the mass rearing of parasitoid. After exposure for 1 day, the dish containing the parasitized larvae is removed and replaced with new dish containing fresh larvae. The parasitized larvae are then transferred to a glass jar containing approximately 1 kg of crushed sorghum grains and allowed for further development.

#### 6. Mass rearing of larval parasitoid, *Goniozus nephantidis*

It is a larval parasitoid and can be reared on the host insect coconut black headed caterpillar. Adult parasitoids are released in glass tubes for mating and 30% sugar solution is provided as food. After mating, one female is taken in a specimen

tube with medium sized black headed caterpillar for parasitization. The parasitoid lays 10-15 eggs on host larval body surface. On hatching the grubs feed on the host larval contents from outside and kill them. The grubs are collected and transferred to setting paper strips in which they construct silken cocoons.

#### 7. Mass rearing of egg-larval parasitoid, *Chelonus balckburni*

It is an egg-larval parasitoid. It is reared on *Corcyra* eggs. It parasitizes the eggs but life cycle is completed on larvae. Fresh eggs of *Corcyra* (0 - 24 hr old) are pasted on Trichocard then it is exposed to newly emerged parasitoids in plastic container at 100 : 1 ratio to avoid super parasitism. The container is covered with muslin cloth. Droplet of honey is provided as food to adults. After 1 day of exposure to the parasitoid, the parasitoid and the parasitized eggs are transferred into another jar containing 500 g of broken well sterilized sorghum grain. The parasitoid develops inside the *Corcyra* larvae and spin small white cocoon adjacent to the carcass of the consumed host and finally adult emerges out in the jar. Everyday the adults are collected with aspirator.

#### 8. Mass rearing of egg - larval parasitoid, *Copidosoma koehleri*

The egg larval parasitoid, *C. koehleri* is an internal, gregarious polyembryonic parasitoid.

It is reared on eggs of potato tuber moth, *Phthorimaea operculella*. The adults of kept in a jar covered the black paper and its mouth is covered with two layers of tissue paper and a markin cloth. After mating the female moth lays eggs in between the two layers of tissue paper. These eggs along with the tissue paper are offered to parasitoids which are fed with fine droplets of honey. After one day the parasitized eggs are removed and placed over prickled potatoes in glass jars. Larvae hatch out and enter the potatoes through the holes and start feeding inside. Before pupation the parasitized larvae emerge and change into mummies and looks like granulated. About 60-100 parasitoids emerge from each granulated larvae.

#### 9. Mass rearing of pupal parasitoids, *Tetrastichus israeli* and *Trichospilus pupivora*

These are pupal parasitoids and can be reared on pupa of coconut black headed caterpillar, *Helicoverpa armigera* and *Spodoptera litura*. The newly emerged adult parasitoids are fed with fine droplets of honey on wax paper and held in glass vials. Fresh pupae are offered for parasitization to the parasitoids. After 2 days the parasitized pupae are transferred in test tubes for parasitoid emergence. These are gregarious parasitoids which completes life cycle in the pupae of the host insect.

**II. Mass multiplication techniques of various predators****1. Mass rearing of *Coccinella septempunctata***

Adults are fed on mealybugs. Five pairs of the predator are released on ten medium sized potatoes well infected with *Ferrisia virgata*, placed in glass jar. Egg masses laid on potato tubers are peeled off gently with the help of sharp blade and left for further development. The eggs about to hatch are placed in tube along with aphids as prey to prevent cannibalism and are reared undisturbed for 2-3 days.

**2. Mass rearing of *Brumus sututralis***

Twenty newly emerged adults of predators are separated and released in a jar containing 20 well infested potato tubers with *F. virgata*. After a week, all the adults were removed and released on other jars having *F. virgata* or *Planococcus pacificus* and the process is continued till adults become under productive (30 – 35 days). The eggs and neonate are left undisturbed till pupation and adults are collected after emergence.

**3. Mass rearing of *Cryptolaemus montrouzieri***

It is a promising predator on mealybugs, scale insects and aphids. Red pumpkin is used for the mass multiplication of grapevine mealybug in the laboratory. Well ripen pumpkin is taken and outer surface is sterilized by 0.1 % Dithane M45 and air dried. Release the crawlers of new born mealybugs on the pumpkin and allow them multiply on pumpkin in dark place. A fully infested pumpkin with mealybugs is placed in a rearing cage. Expose the fruits to adult beetle for oviposition and remove the fruits after 48 hours. Larvae upon hatching feed and develop on the mealybugs. The fully grown larvae pupate on the folded paper placed on the floor of the cage. The pupae are collected and kept in separate jar for adult emergence.

**4. Mass rearing of green lace wing, *Chrysoperla carnea***

The larvae are reared on frozen eggs of *Corcyra cephalonica*. Newly hatched larvae are reared in individual vials or plastic cages containing hexagonal cells. On an average 1 cc of *C. cephalonica* eggs are required for rearing of 5-6 larvae of predator. In each hexagonal cell a larva along with the sufficient prey is placed and covered with a layer of white paper for further development and pupation. After one week the cocoons are collected and kept in separate jars for emergence. Newly emerged adults are kept in caged jar with swab of honey (20%) and pollen grains of castor. The jars are covered with wet black cloth since these prefer to lay eggs on black cloth. The stalked eggs are laid on the black sheet. The eggs are destalked by brushing with sponge piece. The egg sheets can be stored at 10 °C for 21 days. On the 3<sup>rd</sup> day the eggs turn brown and ready to hatch.

## 5.9 BIO - CONTROL ORGANIZATIONS IN WORLD AND INDIA

### ■ Bio - control organizations in world

#### 1. International Organization for Biological Control (IOBC)

The International Organization for Biological and Integrated Control of Noxious Animals and Plants (usually referred to as “The International Organization for Biological Control” or “IOBC”) is a professional organization affiliated with the International Union of Biological Sciences (IUBS).

IOBC was established in 1956 to promote environmentally safe methods of pest and disease control in plant protection.

The scientific journal Entomophaga (now superseded by BioControl) is the official journal of the organization. In 1971 Global IOBC was reestablished with six regional stations

There are 6 regional sections world - wide under IOBC

1. Asia and Pacific Regional Section (APRS)
2. Afrotropical Regional Section (ATRS)
3. East Palearctic Regional Section (EPRS)
4. Nearctic Regional Section (NRS)
5. Neotropical Regional Section (NTRS)
6. West Palearctic Regional Section (WPRS)

The IOBC promotes the development of biological control and its application in integrated pest management (IPM).

The IOBC collects, evaluates and disseminates information about biological control and promotes national and international action concerning research, training of personnel, coordination of large-scale application and public awareness of the economic and social importance of biological control. The IOBC arranges conferences, meetings and symposia, and takes other action to implement the general objectives of the organization.

#### 2. Association of National Biological Control Producers (ANBCP), USA

A nonprofit organization for quality standards and educating the agricultural and academic communities about the importance of biological pest controls for pest management. Goals of this organization are to strengthen the natural enemy production industry and promote research and education on the use of natural enemies.

**List of biological control stations in the world**

| S.No. | Country   | Stations                                                                                                                                                 |
|-------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1     | Australia | CSIRO, Canberra and Sydney                                                                                                                               |
| 2     | Canada    | Canada Department of Agricultural Research, Branch, Belleville                                                                                           |
| 3     | France    | European Biological Control Laboratory (EBCL) (United States Department of Agriculture (USDA), Agricultural Research Service (ARS), Montpellier, France) |
| 4     | Germany   | Institute für biologische Schädlingsbekämpfung, Darmstadt                                                                                                |
| 5     | Japan     | Fac of Agr Kyushu University, Fukuda                                                                                                                     |
| 6     | Mauritius | Department of Agr., Reduit                                                                                                                               |
| 7     | Pakistan  | CIBC, Rawalpindi                                                                                                                                         |
| 8     | Trinidad  | CIBC, St. Augustine                                                                                                                                      |
| 9     | USSR      | Ministry of Agriculture, Tashkent                                                                                                                        |
| 10    | USA       | Insect Bio control Laboratory Center, Beltsville, MD                                                                                                     |

**■ Bio - control organization in India**

Nation Bureau of Agriculturally Important Insects (formely Project Directorate of Biological control (PDBC)) was established in 1993 at Bangalore, Karnataka, India.

### 5.10 SUCCESSFUL CASES OF BIOLOGICAL CONTROL OF PESTS

Important examples of successful biological control of insect pests of agricultural crops by use of introduced natural enemies in India and with in the country

| Crop                                           | Insect pest                                                                                   | Natural enemy                                                                                          | Predator or parasitoid | Country from where imported |
|------------------------------------------------|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|------------------------|-----------------------------|
| Apple                                          | Woolly apple aphid,<br><i>Eriosoma lanigerum</i><br>(Hausmann)<br>(Homoptera : Aphididae)     | <i>Aphelinus mali</i><br>(Haldeman)<br>(Hymenoptera : Aphelinidae)                                     | Parasitoid             | England                     |
| Early black Wattle,<br><i>Acacia decurrens</i> | Cottony cushion scale,<br><i>Icerya purchasi</i><br>Maskell<br>(Homoptera : Margarodidae)     | <i>Rodolia cardinalis</i><br>Mulsant (Coleoptera : Coccinellidae)                                      | Predator               | USA                         |
| Apple                                          | San Jose scale,<br><i>Quadraspidiotus perniciosus</i> (Comstock)<br>(Homoptera : Diaspididae) | <i>Encarsia perniciosi</i><br>(Hymenoptera : Aphelinidae)<br><i>Prospaltella perniciosi</i><br>(Tower) | Parasitoid             | China                       |
| Apple                                          | San Jose scale,<br><i>Quadraspidiotus perniciosus</i><br>(Diaspididae)                        | <i>Aphytis diaspidis</i> How<br>(Hymenoptera : Aphelinidae)                                            | Parasitoid             | USA                         |
| Castor                                         | Castor semi - Looper<br><i>Achaea janata</i><br>Linnaeus<br>(Lepidoptera :Noctuidae)          | <i>Telenomus remus</i>                                                                                 | Parasitoid             | New Guinea                  |
| Coconut                                        | <i>Oryctes rhinoceros</i><br>(Linnaeus)<br>(Coleoptera : Dynastidae)                          | <i>Platyperis laevicollis</i><br>(Distant)<br>(Hemiptera : Reduviidae)                                 | Predator               | Zanzibar (Tanzania)         |
| Citrus                                         | Common mealybug,<br><i>Planococcus citri</i><br>(Risso)<br>(Pseudococcidae)                   | <i>Leptomastix dactylopii</i><br>(Encyrtidae)                                                          | Parasitoid             | Trinidad, West Indies       |

|                                           |                                                                                                                                                       |                                                                                                                                                                                        |             |                                          |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|------------------------------------------|
| Guava,<br>Papaya,<br>Mango                | Spiralling Whitefly,<br><i>Aleurodicus dispersus</i><br>Russell<br>(Aleyrodidae)                                                                      | <i>Aphelinid Encarsia</i><br><i>guadeloupae</i> and <i>E. sp.</i><br><i>nr. meritoria</i>                                                                                              | Parasitoids | Minicoy<br>Island of<br>Laksha-<br>dweep |
| Subabul                                   | Subabul psyllid<br><i>Heteropsylla cabana</i><br>Crawford (Psyllidae)                                                                                 | <i>Curinus coeruleus</i><br>Mulsant<br>(Coleoptera :<br>Coccinellidae)                                                                                                                 | Predator    | Thailand                                 |
| Fruit crops,<br>coffee and<br>ornamentals | Mealybugs<br>( <i>Planococcus citri</i> ,<br><i>P. lilacinus</i> , <i>Ferrisia</i><br><i>virgata</i> ,<br><i>Maconellicoccus</i><br><i>hirsutus</i> ) | <i>Cryptolaemus</i><br><i>montrouzieri</i><br>(Coleoptera :<br>Coccinellidae)                                                                                                          | Predator    | Australia                                |
| Citrus                                    | <i>Planococcus citri</i><br>and <i>P. lilacinus</i>                                                                                                   | <i>Leptomastix</i><br><i>dactylopii</i><br>(Hymenoptera :<br>Encyrtidae)                                                                                                               | Parasitoid  | Trinidad,<br>West<br>Indies              |
| Coconut                                   | Coconut leaf eating<br>caterpillar, <i>Opisina</i><br><i>arenosella</i>                                                                               | <i>Stomatomyia</i> ,<br><i>bezziana</i> (Diptera :<br>Tachinidae)                                                                                                                      | Parasitoid  | Sri Lanka                                |
| Coffee                                    | Coffee berry borer<br><i>Hypothenemus hampei</i><br>(Ferrari)<br>(Coleoptera :<br>Curculionidae)                                                      | <i>Phymastichus coffea</i><br>(Hymenoptera :<br>Eulophidae)<br><i>Prorops nasuta</i><br>(Hymenoptera :<br>Bethyridae)                                                                  | Parasitoid  | Columbia                                 |
| Potato                                    | Potato tuber moth<br><i>Phthorimaea operculella</i><br>(Lepidoptera : Gelichiidae)                                                                    | <i>Bracon gelechiae</i><br>(Hymenoptera :<br>Braconidae)<br><i>Chelonus blackburni</i><br>(Hymenoptera :<br>Braconidae)<br><i>Copidosoma koehleri</i><br>(Hymenoptera :<br>Braconidae) | Parasitoid  | Canada<br><br>Hawaii<br><br>Peru         |

|                                                               |                                                                                                   |                                                                                                               |                   |                     |
|---------------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-------------------|---------------------|
| Tomato and Cotton                                             | American bollworm, <i>Helicoverpa armigera</i> (Lepidoptera : Noctuidae)                          | <i>Eucelatoria bryani</i> (Diptera : Tachinidae)                                                              | Parasitoid        | USA                 |
| Cotton and Okra                                               | Pink bollworm, <i>Pectinophora gossypiella</i> (Lepidoptera : Gelichiidae)                        | <i>Bracon kirkpatricki</i> (Hymenoptera : Braconidae)                                                         | Parasitoid        | USA                 |
| Sugarcane                                                     | Sugarcane inter node borer, <i>Chilo sacchariphagus indicus</i> (Kapur) (Lepidoptera : Crambidae) | <i>Diatraeophaga striatalis</i> (Diptera : Tachinidae)                                                        | Parasitoid        | Indonesia           |
| Sugarcane                                                     | Sugarcane stalk borer, <i>Chilo auricilius</i> Dudgeon (Lepidoptera : Pyralidae)                  | <i>Cotesia flavipes</i> (Hymenoptera : Braconidae)                                                            | Parasitoid        | Indonesia           |
| Sugarcane                                                     | Sugarcane pyrilla, <i>Pyrilla perpusilla</i> Walker (Hemiptera : Fulgoridae)                      | <i>Epiricania melanoleuca</i> Fletcher (Lepidoptera : Epipyropidae)                                           | Ecto - Parasitoid | With in the country |
| Sugarcane                                                     | Sugarcane top borer, <i>Scirpophaga excerptalis</i>                                               | <i>Isotima javensis</i>                                                                                       | Parasitoid        | With in the country |
| Tobacco and vegetables                                        | Tobacco caterpillar, <i>Spodoptera litura</i> (Lepidoptera : Noctuidae)                           | <i>Steinernema carpocapsae</i> (Rhabditida : Steinernematidae)                                                | Parasitoid        | Czech Republic      |
| Beans, Okra and Strawberry                                    | Spider mites, <i>Tetranychus</i> spp.                                                             | <i>Amblyseius chilenensis</i> (Acari : Phytoseiidae)<br><i>Phytoseiulus persimilis</i> (Acari : Phytoseiidae) | Predator          | USA<br>UK           |
| Ornamen-<br>tals,<br>vegetables<br>and<br>leguminous<br>crops | Gaint African snail, <i>Achatina fulica</i> (Pulmonata : Achatinidae)                             | <i>Euglandina rosea</i> (Stylommatophora : Oleacinidae)                                                       | Predator          | Bermuda             |



## 5.11 ENTOMOPHILIC PATHOGENS

The various entomophilic pathogens which are used for the control insect pests are

- |                |              |
|----------------|--------------|
| 1. Bacteria    | 2. Viruses   |
| 3. Fungi       | 4. Protozoa  |
| 5. Rickettsiae | 6. Nematodes |

### 1. Bacteria

Entomopathogenic bacteria are classified as spore formers and non spore formers (Ex: *Pseudomonas* spp.) which are further subdivided into obligate spore formers (Ex: *Bacillus popillae*) and facultative spore formers. The facultative spore formers could be crystal forming or non crystalliferous (Ex: *Bacillus cereus*). The spore forming bacteria are used in insect control than the non spore forming bacteria. Among the spore formers, the crystalliferous are used for the insect control than the non crystalliferous because the toxic nature of the crystals they produce. The best studied example species among the crystalliferous bacteria is *Bacillus thuringiensis* (*Bt*).

#### ***Bt* mode of action**

1. Insect eats *Bt* crystals and spores (stomach poison)
2. The parasporal inclusions (delta endo toxins) dissolve in the alkaline pH of insect gut and release protoxins (size from 27 to 140 kDa) which are proteolytically converted into still smaller toxic polypeptides.
3. These polypeptides bind to glycoprotein receptors (specific receptors) on the midgut cell membrane
4. They generate pores in the cell membrane disturbing cellular osmotic balance and causing cells to swell and lyse through a process that has been termed as "Colloid-osmotic lysis"
5. The leakage of ions from midgut to hemolymph results in ionic imbalance in hemolymph which leads to septicemia
6. Multiple toxins will bind and follow these steps, until the insect is paralyzed
7. The insects stops eating (starvation), crystals cause the gut wall to break down, allowing spores and normal gut bacteria to enter the body
8. The insect dies as spores and gut bacteria proliferate in the body

*Bt* action is very specific. Different strains of *Bt* are specific to different receptors in insect gut wall. *Bt* toxicity depends on recognizing receptors, damage to the

gut by the toxin occurs upon binding to a receptor. Each insect species possesses different types of receptors that will match only certain toxin proteins.

### Symptoms

- Larvae becomes inactive, stops feeding
- Regurgitate or have watery excrement
- The head capsule becomes large compared to body size
- The larva becomes flaccid and dies, usually within days or a week
- The body contents turn brownish-black as they decompose

### Uses

*Bacillus thuringiensis* var. *kurstaki* is used against Lepidoptera

*Bacillus thuringiensis* var. *galleriae* is used against wax moth

*Bacillus thuringiensis* var. *sandiego* and *Bacillus thuringiensis* var. *tenebrionis* are used against beetles and weevils

*Paenibacillus popilliae* is used against several species of white grubs including *Holotrichia consaguinea* and *Leucopholis coneophora* on groundnut and *L. lepidophora* on sugarcane

## 2. Viruses

Baculoviruses are the most common and most widely studied group of viruses pathogenic for insects. Baculoviruses are species or genus specific, except *Autographa californica* nuclear polyhedrosis virus. Viruses are obligate parasites hence need host for multiplication. These are composed primarily of double-stranded DNA. An infective baculovirus particle (*virion*) is protected by protein coat called a *polyhedron*.

The genus NPV is characterized by the presence of polyhedral shaped viral occlusions (polyhedra) containing randomly occluded viral particles. Polyhedroses are characterized by the formation of polyhedron shaped inclusion bodies in the infected tissues of the host.

The genus granuloses virus (GV) has one nucleocapsid per envelope and has granule shaped viral occlusions (capsules) containing one or rarely 2 or more virions.

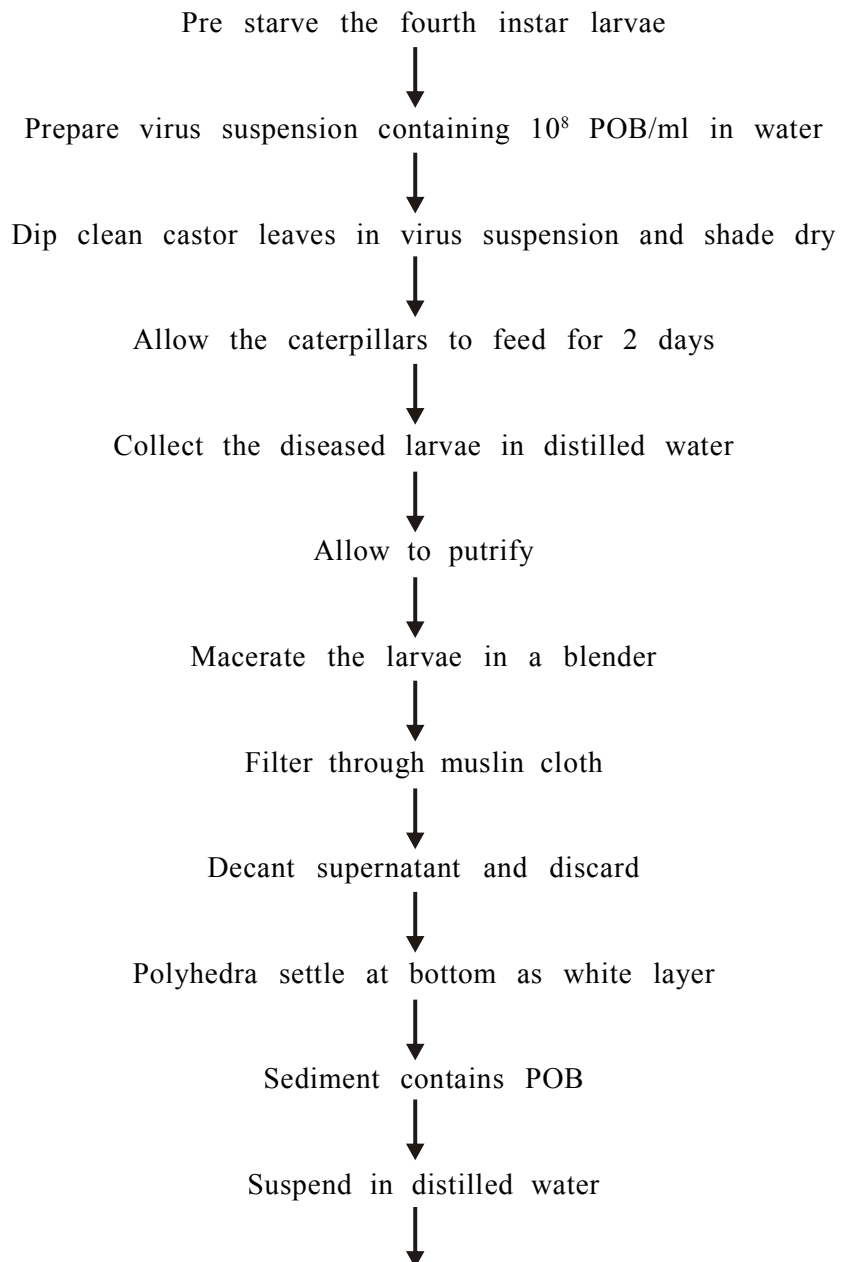
The non occluded baculovirus has one nucleocapsid per envelope and has no occlusions bodies. *Oryctes* non occluded virus infection in rhinoceros beetle, *Oryctes rhinoceros* causes disease known as Malayan disease.

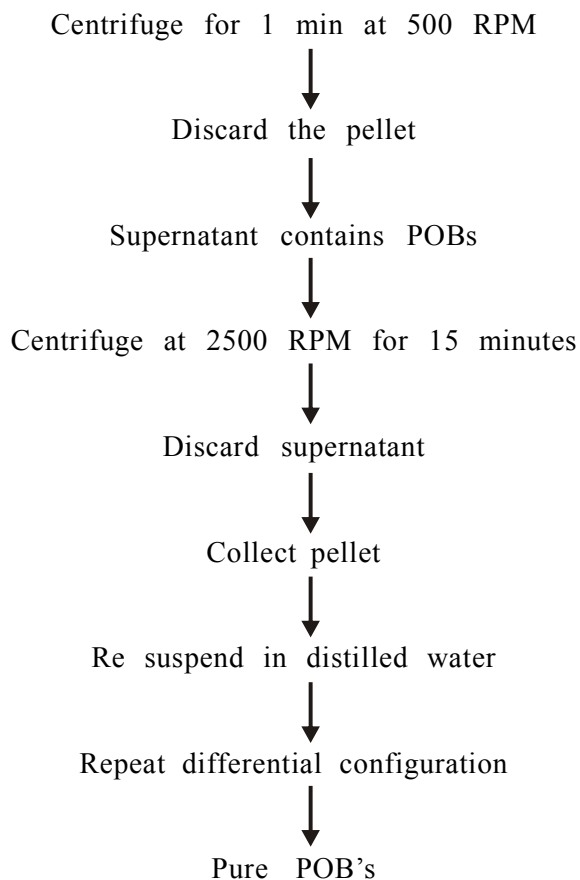
Infection by baculovirus begins when an insect eats virus particles on a plant.

➤ **Mass production of NPV of *Spodoptera litura***

Mass rearing of *Spodoptera litura* can be done on castor leaves in the laboratory.

The steps involved in the mass production of *Sl*-NPV are





The dose of virus is expressed as larval equivalent (LE) and one LE is  $2 \times 10^9$  POB. One LE can be obtained from 3 fully grown up and virus infected larvae.

#### **Mode of action of Baculoviruses**

- The NPV which enters the insect gut, lyses in the alkaline environment of the midgut, releasing virions
- Virions invade the columnar cells of midgut epithelium and integrate DNA into the nucleus of midgut cells
- Later the viral DNA takes over control of the cellular machinery to reproduce itself
- The progenies released into the haemocoel from the midgut cells are more infectious than the poly hedra inclusion bodies (PIBs) and mediate disease spread within the insect body

- A rapid spread of infection in the insect body leads immediately to cessation of feeding followed by death.
- Death from a virus infection usually occurs within three to eight days

#### Symptoms

- They have a characteristic shiny-oily appearance and stop feeding
- They climb to the top of the crop canopy, become limp, and hang from the upper leaves or stems, hence the common name “caterpillar wilt” or “tree top” disease
- They are extremely fragile to the touch, rupturing to release fluid filled with infective virus particles
- NPV - infected larvae may initially turn white and granular or very dark

#### Uses

- NPVs of *Amsacta albistriga* and *A. moorei* are used on groundnut for the control of red hairy caterpillars
- *Ha - NPV* is used for the control of *Helicoverpa armigera* on chickpea and groundnut
- *Sl - NPV* is used for the control of *Spodoptera litura* on tobacco, groundnut, black gram and cotton
- GV of *Chilo infuscutellus* is used for the management of shoot borer on sugarcane

### 3. Fungal pathogens

These reproduce sexually in soils and asexually in insect hosts. In its asexual form it produces spores known as conidia which are wind dispersed. Once they are released they may land upon another insect host, or once again return to the soil where they reproduce sexually.

Insect-pathogenic fungi usually need moisture to enable infection, and natural epizootics are most common during wet or humid conditions. The effectiveness of these fungi against pest insects depends on having the correct fungal species and strain with the susceptible insect life stage, at the appropriate humidity, soil texture (to reach ground-dwelling pest species), and temperature. The fungal spores, which can be carried by wind or water, must contact the pest insect to cause infection. Unlike bacterial and viral pathogens of insects, fungal pathogens infect the insect with contact and do not need to be consumed by their host to cause infection.

#### Mode of action of fungi

- When spores of the fungus come in contact with the cuticle (skin) of susceptible

insects, they germinate and penetrate the cuticle either by germ tube or by infection pegs form appresoria and grow directly through the cuticle to the inner body of their host

- The fungus proliferates throughout the insect's body, producing toxins and draining the insect of nutrients, eventually killing it
- Death is caused by tissue destruction and, occasionally, by toxins produced by the fungus. Once the fungus has killed its host, it grows back out through the softer portions of the cuticle, covering the insect with a layer of mold
- This downy mold produces millions of new infective spores that are released to the environment

### Symptoms

- Infected insects stop feeding and become lethargic
- They may die relatively rapidly, sometimes in an upright position still attached to a leaf or stem
- The dead insect's body may be firm and "cheese-like" or an empty shell, often but not always with cream, green, red, or brown fungal growth, either enveloping the body or emerging from joints and body segments.

### Uses

- *Beauveria bassiana* causes a disease known as the white muscardine. It is effective against European corn borer, codling moth, cabbage caterpillar and whitefly.
- *Metarhizium* spp. causes a disease known as green muscardine. It is effective against rootworm, white grubs, and some root weevils
- *Verticillium lecanii* is used against whitefly and thrips and aphids, especially in greenhouse crops.
- *Nomuraea rileyi* is used against green clover worm, cabbage looper, cabbage worm, armyworms, corn earworm, and tobacco budworm.
- *Hirsutella thompsonii* and *Neozygites floridana* are used against mites.

## 4. Protozoa pathogens

### Mode of Action

Most microsporidia must be eaten to infect an insect. The pathogen enters the insect body via the gut wall, spreads to various tissues and organs, and multiplies, sometimes causing tissue breakdown and septicemia. These are relatively slow acting organisms, taking days or weeks to debilitate their host. One advantage of this

type of infection is that the weakened insects are more likely to be susceptible to adverse weather and other mortality factors.

### Symptoms

- Infected insects may be sluggish and smaller than normal
- Reduced feeding and reproduction, and difficulty in molting
- Death may follow if the level of infection is high

### Uses

- These are used against caterpillars, locusts, grasshoppers
- *Nosema locustae* is used for the control of grasshoppers and crickets
- *Vairimorpha necatrix* is used for the control of corn earworm and European cornborer, various armyworms, fall webworm, and cabbage looper
- *Nosema melolonthae* is used against chaffer beetles
- *Farinocystis triboli* is used against red flour beetle

Protozoa kill the insects either directly or by reducing the fecundity of the adult. Their effect on host is chronic. They prolong the larval life in the field, thus exposing the insect longer to predators and parasitoids. These are called debilitating infections. They are always associated with other pathogens.

## 5. Rickettsiae

The pathogenic rickettsiae differ mainly from bacteria in that they are Gram negative, obligate intracellular pathogens with typical bacterial cell walls and no flagella.

*Rickettsia* is a genus of non-motile, Gram-negative, non-sporeforming, highly pleomorphic bacteria that can present as cocci (0.1  $\mu\text{m}$  in diameter), rods (1 – 4  $\mu\text{m}$  long) or thread-like (10  $\mu\text{m}$  long). Obligate intracellular parasites, the *Rickettsia* survival depends on entry, growth, and replication within the cytoplasm of eukaryotic host cells (typically endothelial cells). Because of this, *Rickettsia* cannot live in artificial nutrient environments and are grown either in tissue or embryo cultures.

### Mode of action

When ingested the infectious elementary forms penetrate the insects midgut wall and replicate in tissues

The small rickettsiae within cytoplasmic vacuoles undergo transformations to bacteria-like forms that multiply by binary fission

Some cells are pleomorphic and form the characteristic protein crystals

All infected cells undergo lysis and masses of rickettsiae, crystals and rickettsiae filled vacuoles are released into the hemolymph

#### Uses

- *Rickettsiella popilliae* is used against Japanese beetle causing blue disease
- *Rickettsiella melolontha* is used against scarabaeid beetles

### 6. Nematode pathogens

Entomopathogenic nematodes (EPNs) are soil-inhabiting, lethal insect parasitoids, live inside the body of their host, and so they are designated endoparasitic. The most commonly studied genera are those that are useful in the biological control of insect pests, the Steinernematidae and Heterorhabditidae.

#### Mode of action

Steinernematidae and Heterorhabditidae are obligate pathogens. The only stage that survives outside of a host is the non feeding third stage infective juvenile or dauer juvenile (IJ). The IJs of Steinernematidae and Heterorhabditidae carry bacterial symbiont of genus *Photorhabdus* and *Xenorhabdus* respectively in their intestinal tract. After locating the suitable host the IJs invade it through natural openings such as mouth, spiracles, anus or thin areas of the host cuticle and penetrate into the host hemocele. The IJs recover from their developmental arrestment, release the symbionts and bacteria and nematodes cooperate to overcome the host immune response. The bacteria propagate and produce substances that rapidly kill the host and protect the cadaver from colonization by other microorganisms. The nematode starts developing, feed on the bacteria and host tissues metabolized by the bacteria, and go through 1-3 generations. Depleting food resources in the host cadaver leads to the development of a new generation of IJs that emerge from the host cadaver in search of a new host.

The most commonly used EPNs are *Steinernema carpocapsae* and *Heterorhabditis bacteriophora*. These are used against soil inhabiting insect pests and tissue borers. These are susceptible to desiccation and hence soil moisture must be high to achieve full benefit from EPN application

#### Uses

- These are used against flea beetles, root weevils and root worms
- These are used against white grubs and cut worms
- These are used against army worms, stem borers and gram pod borer



## 5.12 MICROBIAL INSECTICIDES AND THEIR FORMULATIONS

Microbial control refers to the exploitation of disease causing organisms to reduce the population of insect pests below the damaging levels. The various organisms which are used in microbial insecticides are bacteria, viruses, fungi, protozoa, rickettsiae and nematodes

### List of commercially available microbial insecticidal formulations

| Agent    | Microorganism                                         | Trade names of microbial insecticides                                  | Effective against           |
|----------|-------------------------------------------------------|------------------------------------------------------------------------|-----------------------------|
| Bacteria | <i>Bacillus thuringiensis</i> var. <i>kurstaki</i>    | Biobit, Dipel, Thruicide, Foray, Novodor, Halt, Biolep, bioasp, Delfin | Lepidoptera                 |
|          | <i>Bacillus thuringiensis</i> var. <i>galleriae</i>   | Spicturin                                                              | Lepidoptera                 |
|          | <i>Bacillus thuringiensis</i> var. <i>tenebrionis</i> | Di Terra, M - one, M-Trak, Novovdor, Trident                           | Coeloptera                  |
|          | <i>Bacillus thuringiensis</i> var. <i>israelensis</i> | Acrobe, Skeetal, Teknar, Vectobac                                      | Diptera                     |
|          | <i>Bacillus sphaericus</i>                            | Larvicide, Spherimos, Vectobac and Spherifix                           | Mosquitoes and black flies  |
|          | <i>Bacillus popilliae</i>                             | Doom                                                                   | Japanese beetle             |
|          | <i>Bacillus thuringiensis</i> var. <i>aizawai</i>     | Certan, Agree and Xentari                                              | Caterpillars                |
|          | <i>Bacillus thuringiensis</i> var. <i>sandiego</i>    | M - Trak, Foil and Novodor                                             | Colorado potato beetle      |
| Virus    | Nuclear polyhedrosis virus                            | Ha - NPV                                                               | <i>Helicoverpa armigera</i> |
|          | Nuclear polyhedrosis virus                            | Sl - NPV                                                               | <i>Spodoptera litura</i>    |
|          | Nuclear polyhedrosis virus                            | Aa - NPV                                                               | <i>Amsacta albistriga</i>   |

|           |                                  |                                                               |                                                      |
|-----------|----------------------------------|---------------------------------------------------------------|------------------------------------------------------|
|           | Nuclear polyhedrosis virus       | VPN 80                                                        | <i>Autographa californica</i>                        |
|           | Nuclear polyhedrosis virus       | Spodopterin                                                   | <i>Spodoptera littoralis</i>                         |
|           | Nuclear polyhedrosis virus       | SPOD - X                                                      | <i>Spodoptera exigua</i>                             |
|           | Nuclear polyhedrosis virus       | Elcar                                                         | <i>Helicoverpa zea</i>                               |
|           | Nuclear polyhedrosis virus       | Virin, Gypchek                                                | <i>Lymantria dispar</i>                              |
|           | Granulosis virus                 | Cargo virusine, CYD-X, Granusal, Madex                        | <i>Cydia pomonella</i>                               |
|           | Granulosis virus                 | Agrovir                                                       | <i>Agrotis segetum</i>                               |
|           | Granulosis virus                 | PTM baculovirus                                               | <i>Phthorimaea perculella</i>                        |
| Fungi     | <i>Beauveria bassiana</i>        | Mycotrol, Naturalis<br>Conidia, Ostrinol<br>Boverin           | Sucking pests<br>borers<br>Colorado<br>potato beetle |
|           | <i>Beauveria brongniartii</i>    | Betel, Engerlingspilz,<br>Melocont                            | Scarab beetle<br>larvae                              |
|           | <i>Metarrhizium anisopliae</i>   | BIO 1020                                                      | Black vine<br>weevil                                 |
|           | <i>Metarrhizium flavoviride</i>  | Bio - Blast<br>Green muscle                                   | Termites                                             |
|           | <i>Verticillium lecanii</i>      | BioGreen                                                      | Locusts,<br>grasshoppers                             |
|           | <i>Paecilomyces fumosoroseus</i> | Vertalec, Mycotol                                             | Red headed<br>cock chafer                            |
|           |                                  | PFRE - 97, PreFeral                                           | Whiteflies and<br>thrips                             |
| Nematodes | <i>Steinernema carpocapsae</i>   | BioVector Ecomask<br>Exhibit, Vector TL,<br>X-Gnat, NemaStar, | Lepidopterous<br>larvae                              |

|  |                                          |                                                                                                                                   |                          |
|--|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------------|
|  | <i>Steinernema feltiae</i>               | Green commandos,<br>Guardian Helix, Ortho,<br>BioSafe<br>Entonem, Magnet,<br>Nemasys, Scanmask,<br>Stealth, Gnat Not,<br>NemaPlus | Dipterous<br>insects     |
|  | <i>Steinernema scapterisci</i>           | Proactant                                                                                                                         | Adult mole<br>crickets   |
|  | <i>Heterorhabditis<br/>bacteriophora</i> | GrubStake HB,<br>Heteromask, J-3 Max Hb,<br>NemaGreen, NemaTop,<br>Larvanem, Lawn Patrol,<br>Otinem, Soil commandos               | Soil-dwelling<br>insects |

### 5.13 MERITS AND DEMERITS OF MICROBIAL CONTROL

#### ■ Merits

- These are species - specific and hence safe to beneficial insects
- Environmentally safe and safe to non target organisms
- Capability of causing epizootics
- Compatible with other chemical insecticides
- Less chances of development of resistance
- It is self sustaining and so economical
- Cost of development and registration is much less than that of chemical insecticides
- Easy to apply

#### ■ Demerits

- Narrow spectrum
- Efficacy depend on environmental conditions
- Some pathogens (protozoans) are difficult to mass produce
- Necessity of correct timing of application
- Results are not as quick as insecticides
- Necessity to maintain the virulence and viability of the pathogen till use
- Awareness among farmers is needed to adopt

### 5.14 BIOCONTROL AGENTS AND MICROBIAL INSECTICIDES IN IPM

List of promising bio - control agents of various crops and their dosage

| Crop      | Insect pest                                                     | Biotic agent                                          | Dosage                                                           |
|-----------|-----------------------------------------------------------------|-------------------------------------------------------|------------------------------------------------------------------|
| Rice      | Yellow stem borer,<br><i>Scirpophaga incertulas</i><br>(Walker) | <i>Trichogramma japonicum</i> ,<br><i>T. chilonis</i> | 50,000 – 1,00,000 / ha                                           |
|           | Brown plant - hopper,<br><i>Nilaparvata lugens</i> (Stal)       | <i>Cyrtorhinus lividipennis</i>                       | 100 adults or 50-75 nymphs/m <sup>2</sup> at 10 days interval    |
| Cotton    | American bollworm,<br><i>Helicoverpa armigera</i><br>(Hubner)   | <i>Trichogramma chilonis</i>                          | 1,50,000 parasitized eggs/ha                                     |
|           | Pink bollworm,<br><i>Pectinophora gossypiella</i><br>(Saunders) |                                                       |                                                                  |
|           | Spotted bollworm,<br><i>Earias insulana</i><br>(Boisduval)      |                                                       |                                                                  |
|           | American bollworm,<br><i>Helicoverpa armigera</i><br>(Hubner)   | <i>Ha</i> –NPV                                        | 1.5-3.0 × 10 <sup>12</sup> POB / ha<br>(250 - 500 LE)            |
|           |                                                                 | <i>Bacillus thuringiensis</i><br>(Delfin)             | 1.5 kg / ha                                                      |
|           | Tobacco caterpillar,<br><i>Spodoptera litura</i><br>(Fabricius) | <i>Sl</i> - NPV                                       | 1.5 - 3.0 × 10 <sup>12</sup> POB / ha<br>(250 - 500 LE)          |
| Sugarcane | Shoot tissue borer,<br><i>Chilo</i> spp.                        | <i>Trichogramma chilonis</i>                          | 50,000 / ha                                                      |
|           | Shoot borer, <i>Chilo infuscatellus</i> Snellen                 | Granulovirus                                          | 250 LE or 750 viroed larvae (10 <sup>6</sup> – 10 <sup>7</sup> ) |

|           |                                                                                                                                                                                                                                |                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           | <p>Scale insect, <i>Melanaspis glomerata</i> (Green)</p> <p>Leaf hopper, <i>Pyrilla perpusilla</i> (Walker)</p> <p>White grub <i>Leucopholis lepidophora</i></p>                                                               | <p><i>Pharoscymnus horni</i>,<br/><i>Chilocorus nigrita</i>,<br/><i>Sticholotis madgassa</i></p> <p><i>Epiricania melanoleuca</i><br/>Fletcher</p> <p><i>Paenibacillus popilliae</i></p> <p><i>Metarrhizium anisopliae</i></p> | <p>1500 adult beetles or grubs</p> <p>2 - 3 egg masses or 5 - 7 cocoons in 40 selected spots or 4000 to 5000 viable cocoons/ha</p> <p>0.5 kg / ha once at the time of planting</p> <p><math>42.5 \times 10^{10}</math> spores / m<sup>3</sup> once at the time of planting</p> |
| Pulses    | <p><i>Helicoverpa armigera</i> (Hubner)</p> <p>Lab lab pod borer,</p>                                                                                                                                                          | <p><i>Ha</i> – NPV</p> <p><i>Bacillus thuringiensis</i> var. <i>kurstaki</i> (Delfin)</p> <p><i>Aa</i> - NPV<br/><i>Adisura atkinsoni</i></p>                                                                                  | <p><math>1.5 - 3.0 \times 10^{12}</math> POB / ha (250-500LE)</p> <p>1.5 kg / ha</p> <p><math>1.5 - 3.0 \times 10^{12}</math> POB / ha (250 - 500 LE)</p>                                                                                                                      |
| Oil seeds | <p>Mustard aphid, <i>Lipaphis erysimi</i> (Kaltenbach)</p> <p>Groundnut aphid, <i>Aphis craccivora</i></p> <p>Red hairy caterpillar, <i>Amsacta albistriga</i></p> <p>Groundnut white grub <i>Holotrichia consanguinea</i></p> | <p><i>Verticillium lecanii</i></p> <p><i>Chrysoperla carnea</i></p> <p><i>Aa</i> - NPV</p> <p><i>Paenibacillus popilliae</i></p> <p><i>Metarrhizium anisopliae</i></p>                                                         | <p><math>10 \times 10^6</math> spores / ml</p> <p>Release of II instar grubs @ 2000 grubs / acre @ 250 LE / ha</p> <p>0.5 - 1 kg / ha once at the time of planting</p> <p><math>42.5 \times 10^{10}</math> spores / m<sup>3</sup> once at the time of planting</p>             |

|         |                                                                 |                         |                                                        |
|---------|-----------------------------------------------------------------|-------------------------|--------------------------------------------------------|
| Tobacco | Tobacco caterpillar,<br><i>Spodoptera litura</i><br>(Fabricius) | <i>Sl</i> - NPV         | $1.5-3.0 \times 10^{12}$<br>POB / ha<br>(250 - 500 LE) |
|         |                                                                 | <i>Telenomus remus</i>  | 1,20,000 / ha five<br>times at weekly<br>interval      |
|         | Aphids, <i>Myzus persicae</i>                                   | <i>Chrysoperla</i> spp. | 60,000 second<br>instar larvae / ha                    |
|         |                                                                 | <i>Chrysoperla</i> spp. | 6 second instar<br>larvae / plant                      |

*Aa*-NPV- *Adisura atkinsoni* nucleopolyhedrosis virus; *Sl*-NPV *Spodoptera litura* nucleopolyhedrosis virus; *Ha*- NPV- *Helicoverpa armigera* nucleopolyhedrosis virus; LE- Larval equivalent; POB-Polyhedral occlusion bodies

### 5.15 Mode of action of *Bacillus thuringiensis* Cry and Cyt toxins

*Bacillus thuringiensis* (*Bt*) produce insecticidal proteins during the sporulation phase as parasporal crystals. There are two groups of crystal proteins produced by *Bt*. *Cyt* (cytolysins) and *Cry* (crystal delta- endotoxin) toxins. *Cry* proteins are parasporal inclusion (Crystal) proteins from *Bacillus thuringiensis* and are toxic to target insects. Similarly, *Cyt* proteins are parasporal inclusion proteins from *Bacillus thuringiensis* that exhibits hemolytic (Cytolytic) activity or has obvious sequence similarity to a known *Cyt* protein. These toxins are highly specific to their target insects.

Both *Cry* and *Cyt* proteins are pore forming toxins (PFT). *Cry* proteins are specifically toxic to the insect orders Lepidoptera, Coleoptera, Hymenoptera and Diptera, and also to nematodes. In contrast, *Cyt* toxins are mostly found in *Bacillus thuringiensis* serovar *israelensis* (*Bti*) bacteria and used as biological control agents for larvae stages of certain Dipterans.

*Cry* proteins, are globular molecules containing three structural domains and these have protoxins with two different lengths. The C-terminal extension found in the long protoxins is dispensable for toxicity. While, *Cyt* toxins comprise two highly related gene families (*Cyt*1 and *Cyt*2). *Cyt* toxins are also synthesized as protoxins and small portions of the N-terminus and C-terminus are removed to activate the

toxin.

*Cry* proteins consists of three-domain protein family. Domain I (N-terminal domain) is a bundle of seven  $\alpha$ -helices, Domain II consists of three anti-parallel  $\beta$ -sheets and domain III is a  $\beta$ -sandwich. *Cyt* proteins have a single  $\alpha$ - $\beta$  domain comprising of two outer layers of  $\alpha$ -helix hairpins wrapped around a  $\beta$ -sheet.

Steps involved in the mode of action are

- (1) *Cry* and *Cyt* toxins are solubilized and activated
- (2) *Cyt* toxin inserts into the membrane and *Cry* toxin binds to receptors located in the membrane
- (3) Oligomerization of the *Cry* toxin is induced
- (4) Oligomer is inserted into the membrane resulting in pore formation.

- **Mode of action of *Cry* toxins**

The primary action of *Cry* toxins is to lyse midgut epithelial cells in the target insect by forming pores in the apical microvilli membrane of the cells. Toxicity is related to G-protein mediated apoptosis following receptor binding. *Cry* proteins pass from crystal inclusion protoxins into membrane-inserted oligomers that cause ion leakage and cell lysis. Lepidopteran and dipteran insects have a basic pH (up to pH 11) in their midgut lumen. The crystal inclusions ingested by susceptible larvae dissolve in the alkaline environment of the gut, and the solubilized inactive protoxins are cleaved by midgut proteases yielding 60–70 kDa protease resistant proteins. Toxin activation involves the proteolytic removal of an N-terminal peptide. The activated toxin then binds to specific receptors on the brush border membrane of the midgut epithelium columnar cells, before inserting into the membrane. Toxin insertion leads to the formation of lytic pores in microvilli of apical membranes. Subsequently, cell lysis and disruption of the midgut epithelium releases the cell contents providing spores a germinating medium leading to a severe septicemia and insect death.

- **Mode of action of *Cry* and *Cyt* toxins in mosquitoes**

*Bt* subsp. *israelensis* (*Bti*) is highly active against disease vector mosquitoes like *Aedes aegypti* (vector of dengue fever), *Simulium damnosum* (vector of onchocerciasis) and certain *Anopheles* species (vectors of malaria). This bacterium produces crystal inclusions composed of *Cry*4Aa, *Cry*4Ba, *Cry*10Aa, *Cry*11Aa, *Cyt*1Aa and *Cyt*2Ba toxins. As mentioned previously, the mosquitocidal active *Cry* proteins *Cry*11Aa, *Cry*4A and *Cry*4B share similar structures with the lepidopteran active toxin *Cry*1Aa suggesting a similar mode of action of these *Cry* proteins in mosquitoes.

As in lepidopteran insects, in mosquitoes the crystals ingested by susceptible larvae dissolve in the alkaline gut environment, releasing soluble proteins. *Cyt* toxins are also synthesized as protoxins and small portions of the N-terminus and C-terminus are removed to activate the toxin. In the case of *Cyt2Aa*, 32 amino acid residues and 15 amino acid residues from the N-terminal and the C-terminal ends are removed by proteinase K treatment producing a monomeric protein with hemolytic activity.

- **Receptor binding in mosquito midgut membranes**

*Cry* toxins bind to specific protein receptors in the microvilli of the mosquito midgut cells. In contrast, *Cyt* toxins do not bind to protein receptors but directly interact with membrane lipids inserting into the membrane and forming pores or destroying the membrane by a detergent like interaction.

- **Synergism of *Cyt* and *Cry* toxins**

A major threat to the use of *Bt* is the appearance of insect resistance, which has been documented in the field with lepidopteran insects. However, no resistance has been observed in the field in mosquito species controlled with *Bti*. The lack of resistance to *Bti* is due to the presence of the *Cyt1Aa* protein in the crystal. In addition, synergism between *Cyt1Aa* and the *Cry* proteins of *Bti* has been observed; the activity of the *Bti* crystals is much higher than that of the isolated proteins. *Cyt1Aa* protein synergizes *Cry11Aa* toxicity by functioning as a receptor molecule.

- **Applications of *Cry* toxins**

Three major applications of *Bt* toxins are

1. Control of lepidopteran (defoliator) insect pests
2. Control of mosquitoes that are vectors of human diseases
3. Development of transgenic insect resistant plants

Their primary action is to lyse midgut epithelial cells by inserting into the target membrane and forming pores. Like other pore-forming toxins (PFT) that affect mammals, *Cry* toxins interact with specific receptors located on the host cell surface and are activated by host proteases following receptor binding resulting in the formation of a pre-pore oligomeric structure that is insertion competent. In contrast, *Cyt* toxins directly interact with membrane lipids and insert into the membrane. Recent evidence suggests that *Cyt* synergize or overcome resistance to mosquitocidal-*Cry* proteins by functioning as a *Cry*-membrane bound receptor



## 5.16 INVASIVE ALIEN SPECIES

Alien species are non-native or exotic organisms that occur outside their natural adapted ranges and dispersal potential. Some of the alien species become invasive when they are introduced deliberately or unintentionally outside their natural habits into new areas where they express the capability to establish, invade and out compete native species.

Invasive alien species (IAS) is defined as one that has extensive recruitment into a population with out human intervention. Invasive alien species is an alien species which becomes established in natural or semi-natural ecosystems or habitat, an agent of change and threatens native biological diversity.

IAS are also commonly referred to as invasives, aliens, exotics or non-indigenous species. IAS are species, native to one area or region, that have been introduced into an area outside their normal distribution, either by accident or on purpose, and which have colonized or invaded their new home, threatening biological diversity, ecosystems and habitats, and human well-being. The extent to which introduced species may proliferate and spread is affected by the state of the receiving ecosystem. An alien species may find a vacant niche and spread, or it may compete for one already occupied by a native species. Some IAS proliferate because they find no natural enemies in their new habitat. Although some species have invaded habitats on their own, human activity such as exploration, colonization, trade and tourism has dramatically increased the diversity and scale of invasions by alien species.

Invasive alien species occur in all major taxonomic groups. They include viruses, fungi, algae, plants, insects, fish, amphibians, reptiles, birds and mammals.

Common invasive species traits include :

- Fast growth
- Rapid reproduction even at unfavorable conditions
- High dispersal ability
- High compatibility to survive with the alien ecosystem
- High genetic variability
- Phenotypic plasticity (the ability to alter growth form to suit current conditions)
- Tolerance of a wide range of environmental conditions (Ecological competence)
- Ability to live off of a wide range of food types (generalist)
- Strong potential to compete with native species

- Association with humans
- Prior successful invasions

An introduced species might become invasive if it can out compete native species for resources, such as nutrients, light, physical space, water or food. If these species evolved under great competition or predation, the new environment may host fewer able competitors, allowing the invader to proliferate quickly.

Invasion of insects was the result of globalization and the invasive species caused substantial damage to the native flora and fauna, and also resulted in the extinction of species. The globalization has increased international agricultural trade, and movement of seeds and planting materials has enhanced the risk of introduction of alien pests into India. These species, if not accompanied by the natural enemies which keep them in check in their native range, can multiply in large proportion and cause damage to economically important plant species and crop plants.

Normally introduced species often seem to do better in their new home than in their place of origin because of a paucity of natural enemies or competitors.

#### • Effects of Invasion

Introduction of IAS always carries a cost with it, though it may not be apparent always.

- Damages at ecological level include the appearance of a pathogens/vectors and diseases, predation, competition, major habitat modification/destruction/loss, hybridization, decline of native species, loss of biodiversity.
- Damages at economical level include financial loss caused by the above mentioned changes, loss of livelihood and cost of control.
- Damages done to the quality of life include nuisance.
- As much as 80% of imperiled species are threatened by invasive species in many parts of the world and the threats occur everywhere, terrestrial, freshwater and marine ecosystem.

Examples : Invasion by the coconut eriophyid mite, *Aceria guerreronis*, the cotton mealy bug *Phenacoccus solenopsis*, the papaya mealy bug *Paracoccus marginatus*, the eucalyptus gall wasp *Leptocybe invasa* and *Brontispa*, a beetle pest of coconut. In addition to the alien invasives from across political borders, invasion of pests can also occur from one geographic location to another within the same country.

• **List of invasive insects in India**

| Scientific name                                 | Common name           | Year of introduction |
|-------------------------------------------------|-----------------------|----------------------|
| <i>Eriosoma lanigerum</i> (Hausmann)            | Woolly apple aphid    | 1889                 |
| <i>Quadraspidiotus perniciosus</i> Comstock     | San Jose scale        | 1911                 |
| <i>Orthezia insignis</i> (Browne)               | Lantana bug           | 1915                 |
| <i>Icerya purchasi</i> (Maskell)                | Cottony cushion scale | 1921                 |
| <i>Phthorimaea operculella</i> (Zeller)         | Potato tuber moth     | 1937                 |
| <i>Plutella xylostella</i> (Linnaeus)           | Diamond-back moth     | 1941                 |
| <i>Pineus pini</i> (Macquart)                   | Pine woolly aphid     | 1970                 |
| <i>Heteropsylla cubana</i> Crawford             | Subabul psyllid       | 1988                 |
| <i>Liriomyza trifolii</i> Burgess               | Serpentine leaf miner | 1990                 |
| <i>Hypothenemus hampei</i> Ferrari              | Coffee berry borer    | 1990                 |
| <i>Aleurodicus disperses</i> Russell            | Spiraling whitefly    | 1994                 |
| <i>Bemisia argentifolii</i> Bellows and Perring | Silver leaf whitefly  | 1999                 |
| <i>Leptocybe invasa</i> (Fisher and LaSalle)    | Blue gum chalcid      | 2006                 |

On preliminary assessment, 61 species of plants (including 12 species of fungi) and 14 species of insects have been identified invasive having national distribution and 36 species having regional distribution. About 28 species native to India have been found to be invasive to other biogeographical zones.

Examples :

**1. Woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Aphididae: Homoptera)**

This pest was introduced in India during 18<sup>th</sup> century with imported apple rootstock from China. It was first recorded in Conoor during 1889 and in 1909 reported from Kuman Hills of Uttar Pradesh and in 1910 from Shimla. During 1920 it reached a pest status in India.

**2. San Jose scale, *Quadraspidiotus perniciosus* (Comstock) (Diaspididae : Homoptera)**

The scale was native of China, reached India in 1911, and by 1933 had attained pest status in fruit orchards and plantations of poplars and willows.

**3. Lantana bug, *Orthezia insignis* Browne (Orthezidae: Homoptera)**

In 1915 it was introduced into India, Nilgiri region from Sri Lanka or West Indies.

**4. Cottony cushion scale, *Icerya purchasi* Maskell (Margarodidae: Homoptera)**

It was accidentally introduced into India in 1921.

**5. Potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera : Gelechiidae)**

It was introduced with imported potatoes from Italy to India in 1937 and has spread through out India. It is distributed in almost all parts of the world completely cosmopolitans with limited records from Asia and none from South Africa.

**6. Subabul psyllid, *Heteropsylla cubana* Crawford (Psyllidae: Homoptera)**

Native of Central America was introduced into India during 19<sup>th</sup> century, The *Leucaena* psyllid was described from Cuba by Crawford in 1914 and it started its journey in 1983 when outbreaks occurred in Florida and it was also intercepted in Hawaii in 1984. Within a short span of two years it reached Sri Lanka in 1986 crossing the Pacific Ocean and was noticed in Chengalpattu district of Tamil Nadu, India during 1988 and Bangalore during May 1988.

**7. Serpentine leaf miner, *Liriomyza trifolii* (Burgess) (Agromyzidae : Diptera)**

Agromyzid fly, *Liriomyza trifolii* (Burgess) entered India accidentally probably, during 1990-91. The native country of this pest is USA (Florida). It was introduced probably along with cut chrysanthemum flowers during early 1970s to California, USA. The fly was accidentally introduced into Kenya around the same period. Later, it reached the Canary Islands, Malta, southern France and commercial greenhouses in central and northern Europe. It is now very widely spread in most countries including Pakistan and India.

**8. Coffee berry borer, *Hypothenemus hampei* (Ferrari) (Scolytidae : Coleoptera)**

Coffee berry borer is believed to be a native of Northeast Africa, but has spread to many coffee growing countries throughout the tropics. This pest was not known in India till 1990 when it was reported from Gudalur in the Nilgiris

probably introduced accidentally either through coffee brought by refugees from Sri Lanka or through illegally imported coffee seeds. It has now spread into many coffee growing areas of Tamil Nadu (Gudalur and Kilkotagiri), Kerala (Wyanad) and Karnataka (Kodagu).

**9. Spiraling whitefly, *Aleurodicus dispersus* Russell (Aleyrodidae: Homoptera)**

This is a native of Caribbean region and Central America, during 1970s it started spreading from the Central American countries. First reported in Hawaii outside its native range it started spreading westward in Pacific islands to Philippines. It reached Sri Lanka in 1990 and India in 1994.

**10. Whitefly, *Bemisia tabaci* biotype "B"**

In 1999, a new biotype "B" of the whitefly *Bemisia tabaci* which is an effective vector of *Tomato leaf curl virus* has been reported in Kolar taluk of Bangalore and is suspected to have been introduced with imports of horticultural crops. *Bemisia tabaci* has as many as 600 different host plant species apart from being an efficient vector of over 60 plant viruses makes it a highly destructive IAS. Its ability to feed on many different host plants enables whitefly transmitted viruses to infect new plant species.

**11. Coconut mite, *Aceria guerreronis* Keifer**

This pest was first noticed in Mexico in 1965 and later invaded other parts of the world. In India it was first reported in Ernakulam district of Kerala and Pollachi Taluk in Tamil Nadu in 1998. Presently it is distributed in Andhra Pradesh, Karnataka, Kerala, Lakshadweep Islands, Tamil Nadu and all the major coconut growing states. It is one of the major arthropod pests of coconut palm. It builds large dense populations, feeding causes scarring and distortion of fruits and premature fruit drop. Damage due to mite is known to cause losses up to 30% of copra.

**12. The papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera : Pseudococcidae)**

The papaya mealybug was discovered in Manatee and Palm Beach counties in Florida in 1998 and subsequently spread rapidly to several other Florida counties. It is an alien invasive pest, appeared on papaya in Coimbatore, Tamil Nadu during July 2008. Being an aggressive insect pest, this mealybug soon spread to other economic plants like tapioca, mulberry and teak besides attacking more than 100 other plants including weeds. The Papain, Sago and Silkworm industries were threatened by the menace of this alien invasive mealybug. Papaya mealybug is parasitized by a parasite, *Acerophagus papayae*, Noyes & Schauff (Hymenoptera: Chalcidoidea: Encyrtidae) a tiny small wasp. It is

a solitary endoparasitoid of papaya mealybug. This parasitoid is specific to papaya mealybug and affects only early stage (II instar) nymphs after hatching from the egg. Each female is capable laying 50 eggs in its life time of 35 days. Normally single egg is laid inside a mealybug occasionally more than one egg is also laid.

### • **Management of IAS**

Presently there is no exclusive legislation or policy in India to deal with the IAS. Directorate of Plant Protection, Quarantine and Storage, Faridabad, Ministry of Agriculture is the nodal agency to enforce the regulations. Latest regulations are Plant Quarantine (Regulation of Import into India) Order 2003.

Management of invasive species has there broad approaches

1. Exclusion of IAS from the areas to be protected (Ex: by quarantine or physical barriers)
  2. Eradication
  3. Control
- Prevention of introductions is the first and most cost effective option.
    - I. Exclusion methods based on pathways rather than on individual species provide a way to focus efforts on pathways along which pests are most likely to enter national boundaries and to intercept several potential invaders linked to a single pathway. Three major possibilities to prevent further invasions exists:
      - a. Interceptions based on regulations enforced with inspection and fees
      - b. Treatment of material suspected to be contaminated with non-indigenous species
      - c. Prohibition of particular commodities in accordance with international regulations.

Early detection and eradication of a potential invasive species is often crucial in determining the possibility of eradication or at least of effectively containing a new colonizer. Early detection in the form of surveys may focus on species of concern or on a specific site.
    - II. Eradication is successful and cost effective only in response to early detection of a non - indigenous species. Successful eradication programme should be based on
      1. Mechanical control (picking of snails).
      2. Chemical control (using of pesticides or irradiation methods)
      3. Habitat management (grazing and prescribed burning).

The sterile insect technique used in Japan and Mauritius for eradication of certain species fruit flies is a good example

- III. Control is the last step in the sequence of management options of an IAS when eradication is not feasible. Control involves mechanical, chemical, biological and integrated pest management.

The following action points to be taken to avoid the spread of IAS

1. Develop a unified national system for regulation of all introductions and carrying out rigorous quarantine checks.
2. Strengthen domestic quarantine measures to contain the spread of invasive species to neighbouring areas.
3. Promote intersectoral linkages to check unintended introductions and manage the spread of IAS.
4. Develop a national database on IAS reported in India.
5. Develop appropriate early warning and awareness system in response to new sightings of IAS.
6. Provide priority funding to basic research on managing invasive species.
7. Support capacity building for managing IAS at different levels with priority on local area activities.
8. Promote restorative measures of degraded ecosystems using preferably locally adapted native species for this purpose.
9. Promote regional cooperation in adaption of uniform quarantine measures and containment of invasive exotics.





# Chemical Control and Toxicology

## 6.1 CLASSIFICATION OF INSECTICIDES

■ Different types of classification of insecticides are

- I. Based on toxicity
- II. Based on mode of entry
- III. Based on mode of action
- IV. Based on chemical nature
- V. Miscellaneous compounds

### I. Based on toxicity

- Extremely toxic ( $LD_{50} < 5$ )
- Highly toxic ( $LD_{50} 5 - 50$ )
- Moderately toxic ( $LD_{50} 50 - 500$ )
- Slightly toxic ( $LD_{50} 500 - 5000$ )
- Practically non toxic ( $LD_{50} 5000 - 15000$ )
- Relatively harm less ( $LD_{50} > 15,000$ )

### II. Based on mode of entry

- a. Stomach poisons      b. Contact poisons
- c. Fumigants              d. Systemic poisons

- a. Stomach poisons :** The insecticides which enter the body of the target insect through food are called as stomach poisons. The insecticides applied on the leaves and other parts of the plants, when ingested act on the digestive tract of the insect and bring about kill. These insecticides are very effective against biting and chewing insects.

Ex : *Bacillus thuringiensis*

- b. Contact poisons :** The contact poisons are applied as sprays or dusts, either directly onto the body of insects or to the places frequented by them. They



enter the body of the insects through integument or through spiracles. These insecticides are most effective against piercing and sucking type of insects.

Ex : Fenvalerate

- c. **Fumigants :** Fumigants are toxicants which in the gaseous state penetrate the insect through the tracheal system from which they reach the body tissues and kill the pest species. These are most suited for control of stored grain pests and house hold pests.

Ex : Aluminum phosphide

- d. **Systemic poisons :** These chemical when applied on the plant surface or soil adsorbed by the plant tissue and translocated through the vascular system and enter the body of an insect along with the plant juice or sap sucked by the insect.

Ex : Metasystox

### III. Based on mode of action

- a. Physical poisons                      b. Protoplasmic poisons
- c. Respiratory poisons                d. Nerve poisons
- e. Chitin inhibitors

- a. **Physical poisons :** These toxicants bring about kill of the insects by exerting a physical effect. They cause abrasions in the cuticle, resulting in excessive loss of moisture and insect is killed due to desiccation.

Ex : Diatomaceous earth or inert dusts

- b. **Protoplasmic poisons :** The chemicals which kill the insects by destruction of cellular protoplasm of the midgut epithelium are called as protoplasmic poisons

Ex : Arsenic compounds

- c. **Respiratory poisons :** These chemicals block cellular respiration. They combine with enzymes like cytochrome oxidase and other oxidases containing iron and inhibit their catalytic action.

Ex : HCN, CO

- d. **Nerve poisons :** These chemicals effect the nervous system of the insect and leading to the death of the insect are called nerve poisons. These chemicals are associated with their solubility in tissue lipid and function actively by blocking acetylcholinesterase in insects and mammals.

Ex : Organophosphates and carbamate insecticides

- e. **Chitin inhibitors :** These chemicals affect the enzyme, chitin synthetase during chitin formation and inhibit the chitin synthesis.

Ex : Dimilin (Diflubenzuron)

#### IV. Based on chemical nature

1. Inorganic insecticides
2. Organic insecticides
3. Synthetic organic compounds
4. Miscellaneous compounds

##### 1. Inorganic insecticides : They are of following types

- a) Arsenicals
- b) Fluorine compounds
- c) Other inorganic compounds

##### a) Arsenicals :

- i) Lead Arsenates : They are two types. Acid orthoarsenate and basic orthoarsenate. The acid form is more effective and widely used against beetles and insects having chewing type of mouth parts.
- ii) Calcium arsenate : It is a white powder. It is a stomach poison and is very effective against leaf eating insects.

##### b) Fluorine compounds : Sodium fluoride and sodium fluoaluminate. These are used in baits against chewing insects and house hold pests.

##### c) Other inorganic compounds :

- i) Sulphur : It has strong acaricidal and fungicidal action and is formulated as dusts and wettable powder
- ii) Zinc phosphide : It is grey powder with garlic odour and is used mainly as rodenticides and in baits for mole crickets.

##### 2. Organic compounds

These are divided into a). oils and soaps b). Insecticides of animal origin c). Insecticides of plant origin

##### a. Oils and soaps : Kerosene, diesel, crude oil and pine oils are used against house hold and orchard pests. The soaps are used as wetting agents, stabilizers and spreaders.

##### b. Insecticides of animal origin

**Nereistoxin** : It is isolated from marine annelid, *Lumbrineris heteropoda*. It is a nerve poison. Cartap (padan) is very effective against rice stem borer and cabbage diamond back moth.

##### c. Insecticides of plant origin

- i) Pyrethrum
- ii) Nicotine
- iii) Rotenone
- iv) Neem products

- i) **Pyrethrum** : It is prepared from flowers of *Chrysanthemum cinerariaefolium* and *C. coccineum*. The active ingredient of pyrethrum are four esters derived from two acids and two alcohols  
 Pyrethrolone + chrysanthemic acid = Pyrethrin I  
 Pyrethrolone + pyrethric acid = Pyrethrin II  
 Cinerolone + chrysanthemic acid = Cinerin I  
 Cinerolone + pyrethric acid = Cinerin II  
 It has powerful contact action with rapid knock down effect.
- ii) **Nicotine** : It is extracted from the leaves of tobacco plant, *Nicotiana tabacum* and *N. rustica*. Nicotine sulfate (emulsion) contains 40% nicotine and it is a contact, stomach and fumigant insecticide, mostly used against aphids, jassids and thrips.
- iii) **Rotenone** : It is extracted from the roots of *Derris elliptica*. It is commonly used as fish poison and also used against leaf eating caterpillar.
- iv) **Neem products** : Neem seed oil and neem seed kernel extract (NSKE) are potent insecticides.

### III. Synthetic organic compounds

- a. Organo metal compounds
- b. Chlorinated hydro carbons
- c. Organo phosphorous compounds
- d. Carbamates
- e. Synthetic pyrethroids
- a. **Organo metal compounds** : i) Paris green : It is double salt of copper acetate and copper arsenate. It is used against Colorado potato beetle. ii). Phenolic compounds. These compounds are commonly known as dinitrophenols. Most of them are effective against mites (acaricides).
- b. **Chlorinated hydro - carbons**: These consists of chlorine, hydrogen, carbon and sometimes oxygen. They have long residual stability and are both stomach and contact poisons.  
 Ex : DDT, BHC, Aldrin, Endrin and Endosulfan
- c. **Organo phosphorous compounds** : These are esters of phosphoric and phosphorothioic acids. These consist of phosphorus, carbon, nitrogen, oxygen and sulphur. These insecticides are considered as derivatives of corresponding acids and are classified as  
 Derivatives of phosphorus acid (phosphates), Ex: DDVP, Monocrotophos, Phosphamidon

Derivatives of thiophosphorus acid (phosphorothiolates), Ex: Oxyethyl demeton

Derivatives of phosphoric acid, Ex: Trichlorophon, Butonate

Derivatives of thiophosphoric acid, Ex: Parathion, Methyl parathion, Chlorpyrifos

Derivatives of dithiophosphoric acid, Ex: Malathion, Dimethoate, Phorate

Derivatives of pyro phosphoric acid, Ex: TEPP

Derivatives of phosphonic acid, Ex: Trichlorfon

**Advantages :**

- High insecticidal and acaricidal activity
- Broad spectrum action
- Low persistence and break down into harmless products
- Systemic action of a number of compounds
- Rapid metabolism in vertebrates, do not accumulate in their bodies
- Low dose per unit area

- d. Carbamates :** These insecticides are synthetic derivatives of physostigmine, commonly known as eserine. It is the principal alkaloid extracted from the seeds of Calabar bean, *Phytostroma venenosum*. They have contact and systemic action. They are derivatives of carbamic acid and dithio carbamic acid.

Derivatives of carbamic acid are classified as

Heterocyclic carbamates, Ex : Isolan

Naphthyl carbamates, Ex : Carbaryl

Phenyl carbamates, Ex : Carbofuran

Oxime carbamates, Ex : Aldicarb

**e. Synthetic pyrethroids :**

These are synthetic derivatives of natural pyrethrins. These are lipophilic compounds and are developed for the purpose of improving photo stability and insecticidal activity. These are effective contact insecticides and less effective stomach poisons.

Ex : Cypermethrin, decamethrin

**IV. Miscellaneous compounds**

- a. Neonicotinoides
- b. Thionicotinyl group compounds
- c. Phenyl pyrazoles
- d. Oxadiazine group

- e. Spinosyns
- f. Avermectins
- g. Fumigants
- a. **Neonicotinoides** : These are classified into Chloronicotinyl compounds: Ex: Imidacloprid and acetamiprid. Imidacloprid is effective against sucking pests and termites. Acetamiprid is effective against sucking pests. These inhibit nicotinic acetylcholine by binding with nicotinic acetylcholine receptor.
- b. **Thionicotinyl group compounds** : Ex : Thiomethaxam. Effective against sucking pests. Used as both seed treatment and foliar spray.
- c. **Phenyl pyrazoles** : Ex : Fipronil (Regent). It is broad spectrum insecticide used as both foliar and as soil application. Effective against sucking pests.
- d. **Oxadiazine group** : Ex : Indoxacarb (Avaunt). It is effective against lepidopteron pests. It inhibits the flow of sodium ions into nerve cells leading to paralysis and death.
- e. **Spinosyns** : Isolated from acintomycetes, *Saccharopolyspora spinosa*. The mixture of Spinosyn A and D is called spinosad. Ex: Tracer. It has both fumigant and stomach action. It is effective against lepidopteron pest and stored grain pests.
- f. **Avermectins** : Isolated from soil bacteria, *Streptomyces avermitilis* Ex: Abamectin (Vertimac). These are effective against sucking pests, leaf miner and lepidopteron pests.
- g. **Fumigants** : Toxicants which are used in gaseous form for killing insects are called as fumigants. They are used to kill all kinds of insects irrespective of mouth parts since gases enter the insect body through the spiracles during respiration. They are normally heavier than air and are highly penetrating. They are liposoluble and mostly used against stored grain insects and house hold pests.

#### **Important characteristics of a good fumigant**

- Should have high vapour pressure
- Should not have adverse reaction with fumigated commodities
- Should be toxic to all stages of insects
- Should be able to distribute uniformly without settling down
- Should have distinct warning odour
- Easy to handle and transport
- Non inflammable
- Should not effect the quality and viability of seeds/grains

- It should be safe and cheap

Ex : Aluminium phosphide, HCN, EDCT, Methyl bromide, CS<sub>2</sub>, CCl<sub>4</sub>, Chloropicrin

## 6.2 FORMULATIONS OF INSECTICIDES

### ■ Pesticides formulation

**Definition** (IUPAC, 1986)

Pesticide product offered for sale. It generally comprises active ingredient, adjuvants and other formulants combined to render the product useful and effective for the purpose claimed.

**Adjuvant** : Formulant designed to enhance the activity or other properties of pesticide mixture.

**Formulant** : Any added material in pesticides formulation other than the active ingredient.

**Active ingredient** : It is that portion of a formulation which possesses biological properties.

**Formulation** : It is the process of transforming a pesticidal chemical into a product which can be applied by practical methods to permit its effective, safe and environment use. It is a physical mixture of one or more biologically active chemicals with inert ingredients which provides effective and economical control of pests.

Any treatment of active ingredient that includes its handling, storage, application and effectiveness. Product should have no undesirable effect on any components of ecosystem.

#### ➤ The step involved in the process of formulation are (sequence to be followed)

1. Physical treatment of the material (grinding, mixing, liquification of gases)
2. Combination with other actives or synergists
3. Combination with inerts
4. Addition of adjuvants for special effects

#### ➤ Reasons for why formulation is required

- To provide the requisite dosage and cover
- To provide requisite mass and momentum
- To meet various situation demands (for rat control - bait is required)
- Economy in money and product saved

- Efficacy can be enhanced by increasing the spectrum of activity, by breaking of insect resistance and by delaying the development of resistance
- Safety to operators in handling toxic active ingredients

➤ **Types of formulations**

- I. Solid formulations                      II. Liquid formulations
- III. Gaseous formulations

**Solid formulations** include dusts, granules, wettable powders or water dispersible powders, water dispersible granules and baits

**Liquid formulations** include emulsifiable concentrate (EC), soluble liquid, suspension concentrate and ultra low volume concentrations (ULV)

**Gaseous formulations** include aerosols, fumigants and smoke generators

**I. Solid formulations**

1. Dusts
2. Granules
3. Water dispersible powders (WDP) or Wettable powders (WP)
4. Water dispersible granules (WDG)
5. Baits

**1. Dusts :** These are very finely powdered dry pesticides and consist of active ingredient and carrier. The diameter of the particles is 10 microns. Lesser the size more is the efficacy as they can penetrate into the body segments of the insects and cause abrasion and desiccation. The active ingredient may vary from 0.1 to 25%.

**Advantages**

- Easy in handling and application
- No need of water
- They can be applied in the early morning when the plants are wet with dew

**Disadvantages**

- Less effective
- Loss by drift
- Uniform and thorough coverage is not obtained
- Wind and rain remove quickly
- Irritating to user

2. **Granules** : These are small pellets of highly adsorptive inert material. The size of the granules varies from 4 to 80 mesh. The active ingredient may vary from 1 to 42 %. Granules are used without mixing with water and are usually applied to soil.

These are similar to dusts except for larger particle size. The range of particle size in granule product is designated by 2 figures mesh classification e.g. 16/30 means that virtually all the insecticide granules (90%) will pass through a standard 16 mesh sieve while negligible quantity (10%) will pass through a standard 30 mesh sieve.

#### **Advantages**

- Ready to use, no water or mixing is required
- Problem of drift is very little
- Minimum residue problem
- Less harmful to the natural enemies
- Toxic material is released over a longer period

#### **Disadvantages**

- Not as effective as sprays
- Effect of scorching
- They may need moisture to activate pesticidal action
- Expensive

3. **Water dispersible powders (WDP) or Wettable powders (WP)** : These are fine dusts with wetting and dispersing agents. The active ingredient may vary from 25 to 80 %. These are to be mixed with water at the time of application. These form a suspension when mixed with water. Suspension does not dissolve, hence, requires constant agitation.

4. **Water dispersible granules (WDG)** : This formulation appears as small pellets or granules. It is easier and safer to handle and mix than wettable powders. When the granules are mixed with spray water, they break apart and, with agitation, the active ingredient becomes distributed throughout the spray mixture.

5. **Baits** : Active ingredients mixed with the edible substance preferred by the target pests. Poison baiting is most popular against rats, crabs, slug etc. No special application equipment is required however, cost is high if repeated baiting is needed.

Zinc phosphide is typically added to rodent baits in amount of around **0.75-2%**. Such baits have a strong, pungent garlic-like odor characteristic of phosphine liberated by hydrolysis. The odor attracts rodents, but has a repulsive effect on other animals.



## II. Liquid formulations

1. Emulsifiable concentrate (EC)
2. Soluble liquid
3. Suspension concentrate
4. Ultra low volume concentrations (ULV)
1. **Emulsifiable concentrate (EC)** : The formulation contains the toxicant, a solvent for the toxicant and an emulsifying agent. It is a clear solution and yields an emulsion of oil in water type when diluted with water to spray strength. These are to be mixed with water at the time of application. The spray mixture must be constantly agitated or the pesticide will separate from the water.

### Advantages

- Easy to handle, transport, and store
- Little agitation
- Can use with a wide range of applicators
- Non abrasive to equipment
- Does not plug the equipments

### Disadvantages

- Rapidly absorbed through skin
  - Risk of phyto-toxicity when temperatures are high
2. **Soluble liquid** : It is a suspension of microfine solid particles in an aqueous (water-based) carrier. These are to be mixed with water at the time of application.
  3. **Suspension concentrate or flowable (F)** : Powder in suspension of a liquid carrier. When an active ingredient is neither soluble in water nor in organic solvents, a flowable formulation is developed. The active ingredient is milled with a solid carrier (e.g. inert clay) and subsequently dispersed in a small quantity of water. It has to be diluted with water prior to application.
  4. **Ultra low volume concentrations (ULV)** : These are special formulations almost technical product as such is dissolved in a high grade solvent for micronized droplet applications with out dilution. These are applied with the help of special equipment for controlled droplet applicators (CDA). Total volume dispersed does not exceed 1 or 2 litres/ha, by aerial or ground spray equipments.

## III. Gaseous formulations

1. Aerosols
2. Fumigants
3. Smoke generators
1. **Aerosols** : These are commonly used for garden and house hold (flying) pests. The toxicant is suspended as minute particles (0.1-50 microns) in air as a fog or mist. This is achieved by burning the toxicant or vaporizing it with heat

or atomizing mechanically. The toxicant dissolved in a liquefied gas, if released through a small hole, may cause the toxicant particles to float in air with the rapid evaporation of the released gas. The amount of active ingredient is usually low.

#### **Advantages**

- Easy to use and store

#### **Disadvantages**

- High cost
- Inhalation injury possible
- Drift a problem
- Flammable

2. **Fumigants** : Toxicants which are used in gaseous form for killing the insects are called as fumigants. They are used to kill all kinds of insects irrespective of mouth parts since gases enter the insect body through the spiracles during respiration. Most of the fumigants are liquids and are mixtures of two or more gases.

3. **Smoke generators** : They are used in the form of coil like strips containing pyrethrum oxidant and wood dust. When ignited these coils release vapours. These are most commonly used for the control of mosquitoes.

### **6.3 ENTRY OF INSECTICIDES**

■ Insecticides enter the body of an insect through

1. Cuticle
2. Mouth
3. Spiracles
4. Other exposed sensory organs

The site of entry depends on the type of insecticides. Insecticides having high vapour pressure enter through spiracles or antennae. Lipophilic insecticides gain entry through the cuticle. Insecticides having high polarity enter through mouth.

#### **Entry of insecticides through cuticle**

Insecticides pass through the cuticle to the hemolymph in the body cavity in which they circulate to reach the nervous system. Insecticides also migrate laterally in the integument and reach trachea.

Factors effecting the penetration of insecticide through cuticle are

1. Chemical nature of insecticide
2. Components of the cuticle

3. Nature of carriers and solvents

1. **Chemical nature of insecticide**: Insecticides which are apolar penetrate much faster than polar insecticides.
2. **Components of the cuticle**: Lipid solubility and hemolymph solubility play an important role in the amount of insecticide penetrating the insect cuticle.
3. **Nature of carriers and solvents**: Lipophilic insecticide formulations have oil solvents as carrier. The lighter oils are more suitable as insecticidal carrier than heavier oils. These oils dissolve the epicuticular wax of the cuticular layer and allow the insecticide to enter the target body. Detergents also help the insecticidal penetration in the body of insects by penetrating the outer cement layer of the epicuticle and emulsifying the epicuticular wax.

## 6.4 FACTORS INFLUENCING EFFECTIVENESS OF INSECTICIDE

- Physical properties of formulations
- Penetration of insecticides through the cuticle
- Specific susceptibility to insecticides
- Weather conditions
- Conditions in the field
- Application of pesticides
- Compatibility

## 6.5 COMBINATIONS OF INSECTICIDES

Combinations of insecticides are recommended for the control of insect pests which are resistant to major group of insecticides that are commonly used. These insecticide combinations are usually preferred because these have different mode of action i.e. organophosphates or carbamates with synthetic pyrethroids so that development of resistance to these combination is low. Insecticides which have similar mode of action are not used in insecticides combinations.

**List of insecticides combinations commercially available**

| <b>Insecticide combinations</b>       | <b>Trade name</b> |
|---------------------------------------|-------------------|
| Chlorpyrifos 50% + Cypermethrin 5% EC | Nurelle D 505     |
| Profenophos 40% + Cypermethrin 4% EC  | Polytrin C 44 EC  |
| Chlorpyrifos 16% + Alphamethrin 1% EC | Duet 17 EC        |
| Deltamethrin 1% + Triazophos 35% EC   | Spark 36 EC       |
| Ethion 40% + Cypermethrin 5% EC       | Nagata 45 EC      |
| Deltamethrin 0.8% + Endosulfan 32% EC | Decidan 32.8 EC   |
| Chlorpyrifos + BPMC                   | Brodan 31.5 EC    |
| Fenvalerate + Fenthrothion            | Sumicomb 20 EC    |
| Fenvalerate 3% + Acephate 25% EC      | Koranda 28 EC     |

**6.6 PESTICIDE HAZARDS AND POLLUTION****■ Pesticide hazards**

Hazard refers to the risk or danger of poisoning when a chemical is used or applied. Hazard depends not only on the toxicity but also on the chance of exposure to the toxic amounts of the pesticides.

Pesticides cause hazards in 3 different ways

1. During manufacturing and formulations
2. During application
3. During consumption of treated produce

The hazards are caused in two ways. i). By drift of pesticides polluting the environment such as air, water and soil. ii). Toxic residues on the treated crops.

**The various hazards caused by pesticides are**

1. Hazards to man
2. Resistance development in insects
3. Pest resurgence
4. Secondary pest outbreak
5. Danger to pollinators
6. Effects on wild life
7. Deleterious effect on plants

- 8. Hazards of pesticides residues
- 9. Danger of fire
- 10. Diseases
- 11. Upsetting the ecological balance

1. **Hazards to man** : Insecticides are highly toxic to wide range of animals including man. Persistent insecticides contaminate the environment and reach human being through food, water, milk and meat.
2. **Resistance development in insects** : Insect develop resistance to insecticides and can not be controlled.
3. **Pest resurgence** : Insecticides lead to pest resurgence in two ways. They induce resistance in insects so that after an initial decline they start growing in number again. Insecticides destroy parasites and predators leading to pest resurgence.
4. **Secondary pest outbreak** : The use of broad spectrum insecticides kills the major pest along with the natural enemies. The major pest is controlled, but minor pest becomes major in due course of time. This is called secondary pest outbreak.
5. **Danger to pollinators** : Pollinators like honey bees are adversely affected by indiscriminate use of insecticides resulting in poor yields of fruits and seeds. The danger of pesticides to bees comes not only from direct contact poisoning but also from the taking of poisoned nectar into hives.
6. **Effects on wild life** : Vertebrates and invertebrates are adversely affected by use of insecticides. Water contaminated with insecticides not only kills the aquatic insects which are food to fish but also accumulate in fish body by million fold. Many birds particularly fish eating ones die of insecticidal poisoning.
7. **Deleterious effect on plants** : Some insecticides cause phyto-toxic effects on plants, destroy the germinating power of seeds and impart off flavour to the edible parts.
8. **Hazards of pesticides residues** : Residues of persistent insecticides accumulate in lakes and oceans and undergo biological magnification affecting fishes, birds and human beings at the terminal end of food chain.
9. **Danger of fire** : Inflammable fumigant insecticides cause accidental fires and dust explosions in buildings and godowns.
10. **Diseases** : Pesticidal pollution cause several diseases such as cancer, encephalitis, filariasis etc in human beings and domestic animals.
11. **Upsetting the ecological balance** : Insecticides tend to upset the balance of nature, by destroying wildlife, plants and insects.

➤ **Precaution to reduce hazards**

- Need based use of insecticides and minimum use
- Same insecticide should not be used for long time. It should be substituted with another insecticide
- Indiscriminate use of insecticides should be avoided
- Use of insecticides which are safe to pollinators
- Use of insecticides should be integrated with other control measures
- Highly toxic insecticides should be avoided. Insecticides should be applied under supervision of trained personnel
- During spraying and dusting, labourers, farmers and domestic animals should be evacuated
- Protective clothing should be used while spraying to avoid inhalation and to avoid direct contact with poisons
- Parts of equipments should never be blown with mouth. Instruments used for opening tins and packages of insecticides should not be used for any other purposes
- Smoking and eating should be avoided while applying insecticides. One should take bath after application of insecticides
- Insecticide equipment should not washed near to the source of drinking water
- Safe storage of insecticide formulations
- Field workers should be given first aid training to treat accidental poisoning

■ **Pollution**

Pollution is defined as undesirable change in the physical, chemical or biological characteristics of air, land and water. The pesticides accumulate in the environment and contaminate air, water, soil, plants, animals etc by being transported from one system to another.

➤ **Types of pesticide pollution**

1. Soil pollution
2. Water pollution
3. Air pollution
4. Bioaccumulation

**1. Soil pollution**

The soil is contaminated with the pesticides by deliberate application for controlling soil inhabiting pests or through run off from plants and dumping of empty containers.

Thus soil is reservoir of pesticidal pollution. Pesticides disturb the microbial activity of the soil, having adverse effect on the earthworm population, predatory mites, centipedes and carabid beetles. The microorganisms which play important role in the decomposing the organic matter and increasing the soil fertility are also adversely effected by the insecticides.

## 2. Water pollution

The water sources are being contaminated by surface run off, sediment transport from treated soil, industrial and municipal wastes and direct application of pesticides for the control of aquatic insects. Water contaminated with insecticides not only kills the aquatic insects which are food to fish but also accumulate in fish body by million fold. Many birds particularly fish eating ones die of insecticidal poisoning. Many rivers of the world have been found to contain large amount of insecticides which killed fishes and other aquatic animals.

## 3. Air pollution

Insecticides enter the air by spray drift or volatilization from soil or water. During insecticidal application only a small portion of insecticide is sprayed on the crop and reach the target, the rest either fall on ground or taken up into the atmosphere by air current or turbulence. People around the pesticidal factories are affected by leakage of toxic gases and pesticidal pollution causing different kinds of diseases. The contamination of air during application of pesticides also takes place which pose serious health hazards.

## 4. Bioaccumulation

The accumulation of insecticides in various biological systems is called bioaccumulation. The insecticide enters a biological system mainly by aerial, terrestrial and aquatic routes. When an insecticide enters the food chain its biomagnification takes place at different trophic levels. Maximum accumulation of toxicant is found at the top of the food chain or the last trophic level.

**Factors affecting bioaccumulation are**

- i) **Physiochemical properties of insecticide** : Chemical stability, water and lipid solubility and partition coefficient will determine the bioaccumulation of the insecticides.
- ii) **Competition** : Dilution of toxicant with in ecosystem takes place as result of biological competition. This phenomenon is called biological dilution.
- iii) **Rate of food consumption and speed of elimination** : The uptake of insecticides depends on the quantity of food ingested. Though, smaller animals ingest more amount of toxicant, rate of metabolism and elimination of toxicant is higher. Hence, the toxicant will not accumulate in their body.

➤ **Measures to overcome insecticidal pollution**

- Pesticide manufacturing industries should have safety arrangements
- Pesticide industry should have separate team to handle disastrous situation
- Government should enforce standards of emission and effluents
- Proper training for workers and users for handling hazardous pesticides should be organized from time to time
- Well equipped laboratories for pesticides residue estimation should be set up at different parts of the country
- Commodities having pesticides residues above the tolerance limits should not be allowed in the market for human consumption
- Regular field demonstrations for safe handling of plant protection equipment should be given to the farmers
- Bringing awareness among people about storing, handling and marketing of hazardous pesticides
- Use of recommended pesticides at selective dose at appropriate time

## **6.7 PRECAUTIONS FOR SAFE USE OF PESTICIDES**

➤ **Guide lines for the safe use of pesticides**

**Precautions to be followed before applying the pesticide – General instructions'**

- Know the pest, and how much damage is really being done
- Use pesticides only when really needed
- Seek advice on the proper method of control
- Use only the recommended pesticide for the problem. If several pesticides are recommended, choose the least toxic to mammals and if possible the least persistent
- Read the label including the small print
- Make sure the appropriate protective clothing is available and is used, and person is fully trained in how to apply pesticide
- Check application equipments for leaks calibrate with water and ensure it is in proper working order
- Check that plenty of water is available with soap and towel and that a change of clean clothing is available
- Avoid inhaling pesticide
- The pesticides should be always in locked store



- Warn neighbours of your spray programme, especially if they have apiaries
- Take only sufficient pesticide for the day's application for the store to the site of application
- Do not transfer pesticides into other containers

#### **While mixing pesticide and during application**

- Wear appropriate protective clothing. If contaminated, remove and replace with clean clothing
- Never work alone when handling the most toxic pesticides
- Never allow children and other unauthorized persons near the mixing
- Recheck the instructions on the label
- Avoid contamination of the skin, especially the eyes and mouth
- Liquid formulations should be poured carefully to avoid splashing
- Never eat, drink or smoke when mixing or applying pesticides
- Always have plenty of water available for washing
- Always stand upwind when mixing
- Make sure pesticides are mixed in the correct quantities
- Avoid inhalation of chemical, dust or fumes
- Start spraying near the downward edge of the field and proceed upwind so that operators move into unsprayed areas
- Never blow out clogged nozzles or hoses with mouth
- Never leave pesticides unattended in the field
- Provide proper supervision of those assisting with the pesticide application and have adequate rest periods

#### **After application**

- Return unused pesticide to the store
- Safely dispose of all empty containers and always try to bury/burn the empty containers
- Never leave pesticides in application equipment
- Clean the equipment with plenty of water and return to store
- Remove and clean protective clothing
- Wash well and put on clean clothing. Take shower bath after application
- Keep record of the use of pesticides
- Do not allow other persons to enter the treated area for the required period

### **Precautions for operators**

- If operator feels giddiness, uneasy, he must discontinue spraying / dusting at once
- Operator should not spray / dust more than 4 hours at a stretch in a day
- Operator should not take up spray / dusting work with empty stomach

### **First Aid**

When poisoning occur following measures are to be observed

Call a physician if one can be reached easily. Describe the condition of the patient and if known, the nature of the poison and whether it was swallowed, inhaled or spilled on the skin or eyes. The doctors will advice what to do until he arrives.

If you cannot reach the physician, the first thing to do is to remove the causes of the poisoning. If the poison has been swallowed, induce vomiting by putting the finger or a tongue depressor down the patient's throat until he vomits. Never try to make an unconscious person vomit.

Soothe the throat and stomach and irritated membranes. Give raw eggs, milk or a thin flour paste after the stomach has been emptied. These also serve to absorb poisons.

Give an appropriate antidote. Antidote is a substance that relieves, prevents or counter acts the insecticide concerned. Read the label for specific antidote. In general, for chlorinated hydrocarbon insecticide, perform a gastric lavage and gives saline laxative. The physician may give Phenobarbital or pentobarbital to control convulsions. For organophosphorous insecticides, give atropine sulphate or protopam chloride (Pralidoximechloride and 2-PAM)

If poison has been inhaled, remove patient to open air. Give artificial respiration if patient is not breathing. Mouth to mouth sucking is quickest. Give appropriate antidote as suggested above

If the poison has been spilled on the skin or eyes or clothing, remove the contaminated clothing and wash skin and eyes with plenty of water with or without soap.

## **6.8 INSECTICIDES ACT, 1968**

### **The Insecticide act of India, 1968**

An Act to regulate the import, manufacture, sale, transport, distribution and use of insecticides with a view to prevent risk to human beings or animals, and for matters connected therewith

The act was passed by parliament in 1968 and same was enforced through out the country in August 1971, and the rules were framed there under in October, 1971.

➤ **The objectives of insecticides act are**

1. To register only safe and efficacious pesticides
2. To ensure that the farmers/users get quality product for controlling the pests
3. To prescribe usage of pesticides both from ground and air, and also important precautions for their handling and use
4. To minimize health hazards from the pesticides residues through contaminated food, water and air
5. To ensure that the pesticide industry manufacture, transport, distribute, store and sell the pesticides as per the prescribed regulation, failing which legal action is taken
6. To ensure that the pesticides are properly packed and labeled to avoid any leakage of the hazardous pesticides in transit and to provide enough instructions for their safe handling and use.

➤ **Registration of insecticides**

- (1) Any person desiring to import or manufacture any insecticide may apply to the Registration Committee for the registration of such insecticide and there shall be separate application for each such insecticide.
- (2) Every application under sub-section (1) shall be made in such form and contain such particulars as may be prescribed.

- (3) On receipt of any such application for the registration of an insecticide, the Committee may, after such enquiry as it deems fit and after satisfying itself that the insecticide to which the application relates conforms to the claims made by the importer or by the manufacturer, as the case may be, as regards the efficacy of the insecticide and its safety to human beings and animals, register [on such conditions as may be specified by it] and on payment of such fee as may be prescribed, the insecticide, allot a registration number thereto and issue a certificate of registration on token thereof within a period of twelve months from the date of receipt of the application

(3A) In the case of applications received by it prior to the 31<sup>st</sup> March, 1975, notwithstanding the expiry of the period specified in sub-section (3) for disposal of such applications, it shall be lawful and shall be deemed always to have been lawful for the Registration Committee to dispose of such applications at any time after such expiry but within a period of one year from the commencement of the Insecticides (Amendment) Act, 1977 (24 of 1977):

PROVIDED that nothing contained in this sub-section shall be deemed to make any contravention before the commencement of the Insecticides (Amendment) Act, 1977 (24 of 1977), of a condition of a certificate of registration granted before such commencement, an offence punishable under this Act.

(3B) Where the Registration Committee is of opinion that the insecticide is being introduced for the first time in India, it may pending any enquiry register it provisionally for a period of two years on such conditions as may be specified by it.

(3C) The Registration Committee may, having regard to the efficacy of the insecticide and its safety to human beings and animals, vary of conditions subject to which a certificate of registration has been granted and may for that purpose require the certificate-holder by notice in writing to deliver up the certificate to it within such time as may be specified in the notice.]

- (4) Notwithstanding anything contained in the section, where an insecticide has been registered on the application of any person, any other person desiring to import or manufacture the insecticide or engaged in the business of, import of manufacture thereof, shall on application and on payment of prescribed fee be allotted a registration number and granted a certificate of registration in respect thereof on the same conditions on which the insecticide was originally registered.

## 6.9 METHODS OF TOXICITY TESTING

### ■ Bioassay

Bioassay is made up of two words namely 'bios' means life and 'assay' means determination. It is the determination of response of a chemical on living organism.

Bioassay or biological assay means the measurement of the effect of insecticides on living organism. According to Finney (1952) bioassay means the measurement of the potency of any stimulus which may be physical, chemical, biological, physiological or psychological etc., by means of the reactions which it produces in a living organisms.

### Importance of bioassay

- Bioassay helps in ascertaining the potency of the insecticide
- Relative toxicity of different insecticides can be ascertained
- Insect resistance to different insecticides can be studied
- Micro quantities of insecticidal residues retained by the plants can be deduced
- Formation of toxic metabolite produced from the insecticides can be assured
- New and promising toxicants can be screened
- New formulations can be developed
- Factors influencing the toxicity of insecticides can be known
- It helps to find out the property of synergism or antagonism of a compound

**Different methods of bioassay are**

1. Direct exposure method
2. Aqueous solution method
3. Film or residue deposit method
4. Topical application method
5. Injection method
6. Sandwich method
7. Dipping method
8. Leaf dipping method
9. Fumigation method

1. **Direct exposure method :** The insects are exposed to materials with out extraction. The toxicant may be picked up by insects by feeding, by contact or even as vapour. The mortality counts are made after specific period of time.
2. **Aqueous solution method :** In this method measured quantity of insecticide is mixed with water in a suitable container. Known numbers of insects are released into the container for a definite period and number of insects alive or dead are counted. This method is normally used for aquatic insects like mosquito larvae.
3. **Film or residue deposit method :** The insecticidal solution is deposited on a glass surface or Petri dish. The test insects are then exposed to the film of the toxicant in the Petri dish. The insects pick up the toxicant through its tarsi and gets killed. The mortality is counted after a definite period.
4. **Topical application method :** In this method small amount of toxicant is applied topically on the body of insects by means of topical applicator. Uniform spraying or dusting on the insect body can be done by means of Potter's tower or dusting tower. Mortality counts are taken after a specific time period.
5. **Injection method :** The toxicant is directly injected in the body system of organisms by hypodermic needle. The quantity of toxicant is measured precisely by micrometer.
6. **Sandwich method :** In this method measured amount of insecticide is put in between two leaves and the test insect is allowed to feed on it. It is generally used for leaf eating caterpillars.
7. **Dipping method :** Maggots of some dipterans are dipped in the insecticidal solution for few seconds or minutes depending upon the standardization.
8. **Leaf dipping method :** The leaves are dipped in aqueous solution of insecticides for a definite period, then they are taken out. After few minutes the known numbers of insects are allowed to feed on these leaves and the mortality counts are done after a definite period.

9. **Fumigation method** : For stored grain pests the grains are subjected to fumigation in a closed chamber by suitable preparation of the insecticide for a specified duration.

## 6.10 DETERMINATION OF $LC_{50}$

### ■ Probit analysis

The most common way of estimation of  $LC_{50}$  is from the regression line relating the log dose to a transformed percentage response. There are many transformations of proportions, viz., angular, logit and probit transformations. Of these, a probit transformation is very commonly used.

Probit is the short form of probability + unit.

Prepare different concentrations of test insecticide and release a known number of insects of same age in each concentration. After fixed duration note down the mortality of insects in the treatment as well as in control.

Find out the log value of the concentration of insecticides used, with the help of log table. and denoted as x. Write down the value of actual concentration used in the column 1 and of x in column two of the table 1.

Write down the number of insects released denoted as 'n' for bioassay at a particular concentration in column 3 of the table. With the help of the data on mortality of test insects calculate the percentage of mortality and write in column 4. The corrected mortality can be calculated by using Abbotts formula

$$T - C / 100 - C \times 100$$

Where T = % mortality in the treatment

C = % mortality in the control

Write down the corrected mortality in column 6 of the table.

Obtain the empirical probit value with the help of the data of corrected mortality from the Finney's book of Probit analysis (Table 1). These values are written in column 6 of the table

Plot empirical probit against the log doses (x) on graph paper. Draw a provisional straight line to fit the points, judging the position by eye. While fitting such straight line it should be taken into account that the line passed closely through the points corresponding to the probits of 20 to 80% mortality. Now substitute the actual points plotted on the graph on the straight eye fit line. The shifted points corresponding to log doses (x) would be expected probits (Y) which should be written in column 7 of the table

Using the value of expected probit corresponding with natural percentage of mortality find out weighing coefficients with the help of the Table 2 of the Finney's book.

These weighing coefficients are denoted by 'w' and written in column 8 of the table

With the help of data on expected probit and corrected percentage of mortality find out the value of working probit (Table 4 of the Finney's book). It is denoted by 'y' and written in column 9 of the table

In other columns (10 to 15) of the table the results of the multiplication of data written in columns of the table are to be put in and sum of the data for each dose response filled in these columns be made so as to obtain  $\Sigma nw$ ,  $\Sigma nwx$ ,  $\Sigma nwy$ ,  $\Sigma nwx^2$  and  $\Sigma nwy^2$

Calculate the values of  $\bar{x}$  and  $\bar{y}$

$$\bar{x} = \Sigma nwx / \Sigma nw$$

$$\bar{y} = \Sigma nwy / \Sigma nw$$

Calculate the value of regression coefficient by the help of following formula

$$b = \Sigma xy / \Sigma xx$$

Where

$$\Sigma xy = \Sigma nwx y - (\Sigma nwx) (\Sigma nwy) / (\Sigma nw)$$

$$\Sigma xx = \Sigma nwx^2 - (\Sigma nwx)^2 / \Sigma nw$$

Apply regression equation

$$y = \bar{y} + b (x - \bar{x})$$

Where

Y = Probit of 50 % mortality (From table 1 of Finney's' book)

$\bar{y}$  = means

b = regression coefficient

x = log concentration

$\bar{x}$  = means

Take the antilog of the value x which would be the concentration of insecticide capable of killing 50 per cent population i.e.  $LC_{50}$

The regression equation is also helpful to work out  $LC_{30}$  and  $LC_{90}$  or any other lethal concentration / dose. First find out the empirical probit against the mortality for which lethal concentration is to be determined (from table 1 of Finney's book) and then such probit value be used in place of Y in the regression equation. The antilog of x so worked out from such equation would be the lethal concentration / dose against that particular mortality.

**Data sheet for probit analysis (Table 1)**

| Concentration or dose | Log of concentration or dose (x) | Number of insects released (n) | Mortality per cent | Corrected mortality per cent (P) | Empirical probit | Expected probit (Y) |
|-----------------------|----------------------------------|--------------------------------|--------------------|----------------------------------|------------------|---------------------|
| 1                     | 2                                | 3                              | 4                  | 5                                | 6                | 7                   |

| Weighting coefficient (w) | Working probit (y) | nw          | nwx          | nwy          | nwxy          | nwy <sup>2</sup> | nwx <sup>2</sup> |
|---------------------------|--------------------|-------------|--------------|--------------|---------------|------------------|------------------|
| 8                         | 9                  | 10          | 11           | 12           | 13            | 14               | 15               |
|                           |                    | $\Sigma nw$ | $\Sigma nwx$ | $\Sigma nwy$ | $\Sigma nwxy$ | $\Sigma nwy^2$   | $\Sigma nwx^2$   |

## 6.11 PESTICIDE RESIDUES

The amount of insecticidal chemical initially laid down after application on the surface or substrate is termed as deposit. The deposit after a lapse of time is referred to as residue.

### Methods of residue

**Determination of insecticides residues involves 4 major steps**

1. Sampling
2. Extraction
3. Clean up
4. Analysis

#### 1. Sampling

The sample collected for analysis should possess accuracy, validity, representativeness and variability. Imperfect sampling leads to erroneous conclusion.

#### 2. Extraction

It is a process by which the toxicant is transferred from the treated bulky biological material into a solvent. The selection of solvent depends on the physical and chemical properties of the toxicant which is to be extracted and on the type of substrate where it persists.



There are 3 methods employed for extraction

- a. Surface rinsing : This method is employed for extraction of toxicant from the surface of the substrate.
- b. Soxhlet extraction : This method is employed for extraction of dry samples.
- c. Macerating and blending : This method is used to remove the external and internal residues of insecticides from the treated biological material.

### 3. Cleanup

Isolation of toxicant from interfering substances or solvent is called cleanup.

The following types of clean up procedures are usually employed in residue estimation

- a. Liquid - liquid partitioning
- b. Column, channel and thin layer chromatography
- c. Sweep so - distillation
- d. Selective photo - degradation
- e. High performance liquid chromatography
- f. Chemical means - saponification, oxidation
- g. Physical means - crystallization or freezing

### 4. Analysis

The method of residue analysis are divided into chemical assay and micro bioassay

#### I. Chemical assay :

The commonly used chemical methods are

- i) Spectrophotometric methods
  - ii) Ultraviolet spectrophotometry
  - iii) Visible spectrophotometry
- i) **Spectrophotometric methods** : This technique utilizes the property of selective absorption of radiant energy by chemical substances. The quantitative analysis of insecticides in given sample is based on the Beer and Lambert's Law. Three types of spectro photometric methods are used depending up on the wave lengths.
  - ii) **Ultraviolet spectrophotometry** : This method is used for the determination of residues of BHC, DDT, diazinon and parathion. In this method the commonly used range is from 220 to 380 nanometers.
  - iii) **Visible spectrophotometry** : This method is most commonly used in residue analysis. In this method the range used is from 400 to 600 nanometers.
- Infrared spectro photometry : This method is used for the determination of residues of diazinon and carbophenthion.

- b) Chromatographic methods :** Four types of chromatographic methods are generally used in residue analysis. They are
- Column chromatography
  - Paper Chromatography
  - Thin layer chromatography
  - Gas chromatography
- i) Column chromatography:** This method is widely used for the cleanup of insecticide residue.
- ii) Paper Chromatography:** This method is widely used for the analysis of insecticide residue.
- iii) Thin layer chromatography:** This technique is used in residue analysis for clean up, identification and quantification of some of the organochlorines, organophosphates and carbamates.
- iv) Gas chromatography:** It is mostly used for both qualitative and quantitative analysis of residues of insecticides. This method is very sensitive and can detect the residues as low as nano or picogram level. It is of two types. Gas solid chromatography (GSC) in which the gas is the moving phase and solid is stationary phase, and gas liquid chromatography (GLC) in which stationary phase is a non volatile liquid distributed on a solid support.
- c) Enzyme inhibition method:** This method is extensively used for the analysis of organophosphate and carbamate insecticides. The 3 methods for residue analysis based on enzyme inhibition are potentiometric method, colorimetric method and thin layer chromatography enzyme inhibition method.

#### **Advantages**

- It is very sensitive for organophosphates and carbamate insecticides
- Can be employed where active metabolites of insecticides are produced
- It is a rapid method of analysis

- II. Bioassay :** In this method the living organisms are used for determining the insecticidal residues. Among insects, *Drosophila*, adult house flies and larvae of mosquitoes are commonly selected as test insect.

## 6.12 MODE OF ACTION OF INSECTICIDES

### I. Axonic poisons

Ex : Chlorinated hydrocarbons, Cyclodienes and pyrethroids

Axonic poisons act primarily by interruption of normal axonic transmission of the nervous system. The axon of the nerve cell is an elongated extension of the cell body that transmits nerve impulses to other cells. The nerve impulses are electrical and arise from the flow of positive sodium and potassium ions through the cell membrane, creating a wave like action potential. The action potential is followed by resting potential. These compounds disrupt normal transmission along the axon. These induce changes in axonic membrane permeability, causing repetitive discharges. Such discharges eventually result in convulsions, paralysis and death.

#### a) Mode of action of DDT

DDT causes a violent excitatory neurotoxic system in most insects which leads to uncoordinated movements and DDT jitters. The symptoms of DDT poisoning are characterized by ataxia, hyper excitability, convulsions, paralysis and death. According to Mullins (1954) the size of DDT molecule is such that it fits into the intermolecular space of the interspace resulting into nerve disorders. DDT acts as a wedge in the outer covering of the nerve which keeps the sodium gate open and leaking resulting in repeated discharges or short circuit preventing it from normal nerve condition.

#### b) Mode of action of cyclodiene insecticides

These inhibit ATPases, particularly  $\text{Na}^+$ ,  $\text{K}^+$ -ATPase. The symptoms of poisoning include tremors, convulsions and prostration. They interfere with the balance of sodium and potassium within the neuron. They also involve in the changes in the ion permeability at axonic nerve.

#### c) Mode of action of pyrethroids

The toxic action of pyrethroids is due to the plugging of sodium and potassium channels themselves at the gate, showing the physico chemical process on the nerve membrane. The symptoms of poisoning include excitation, convulsions, paralysis and death.

### II. Synaptic poisons

#### a) Mode of action of nicotine, nicotine sulfate, neonicotinoids and spinosyns

Nicotine, nicotine sulfate and neonicotinoids poison by mimicking acetyl choline at the synapse. The receptors cannot distinguish between acetyl choline and nicotine. This phenomenon results in symptoms similar to the inhibition of acetyl choline

esterase. Symptoms of poisoning are excitation, convulsion, paralysis and death.

**b) Mode of action of formamidines**

Formamidines cause insect death by affecting enzymes involved with other chemical transmitters (including norepinephrine and octopamine) at certain nerve synapses.

**c) Nicotinyl insecticides**

Ex : Imidacloprid and Acetamiprid

These are also called as chloronicotinyls insecticides. These insecticides interact with nicotinic acetylcholine receptors (nAChR) at the central and peripheral nervous systems, resulting in excitation and paralysis, followed by death. These compounds simulate the activity of acetylcholine which results from the inhibition of acetylcholine esterase by organophosphorous compounds. These interact with the nAChR in a structure activity relationship and show strong affinity to the insect receptor.

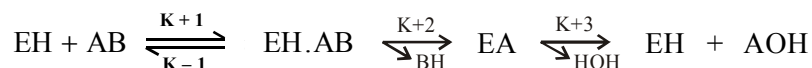
**d) Mode of action of fipronil**

Fipronil acts at the nerve synapse. It acts on GABA receptors, which function to increase chloride ion permeability of neurons, producing a calming effect after nerve firing. Fipronil prevents chloride ions from entering the neuron by blocking the GABA regulated chloride channel.

**e) Mode of action of organophosphates and carbamates**

Toxic phosphoric and carbamic acid esters after penetrating inside the body of insects reach the cholinergic site. These compounds mimic the gross molecular shape of acetyl choline and react with enzyme, acetyl choline esterase. These inhibit acetylcholine esterase by blocking its active sites which are responsible for the hydrolysis of the natural substrate acetyl choline.

In brief the reaction may be written as



Where

EH is enzyme

AB is insecticide (A is phosphorylating group and B is leaving group)

EH.AB is reversible complex

EA is acetylated, phosphorylated, or carbamylated enzyme

BH is leaving group

K+1, K-1, K+2, K+3 represent reaction rates

K+1 / K-1 is called  $K_a$  represent the affinity constant between the enzyme or substrate or inhibitors

The acetyl choline esterase inhibition thus lead to an accumulation of acetyl choline at nerve endings, which causes disruption of nervous activity resulting in producing symptoms of restlessness, hyper excitability, tremors and convulsions, paralysis and death.

➤ **Differences between mode of action of organophosphates and carbamates**

One major difference in the action of organophosphates and carbamates is that inhibition of acetyl choline esterase by carbamates is reversible but not with organophosphates.

For the reactions between enzyme, acetyl choline esterase and organophosphates, the values of  $k+1$ ,  $k-1$  and  $k+2$  are rapid hence the complex EH.AB never accumulates. But the  $k+3$  reaction is slow or nil hence there is no hydrolysis and EA accumulates. Finally the enzyme is not liberated.

For reactions between enzyme, acetyl choline esterase and carbamates the value  $K_a$  is such that there is quick formation of complex EH.AB. The  $k+2$  reaction is low hence there is accumulation of EH.AB. The reaction  $k+3$  is faster compared to organophosphates hence results in hydrolysis of enzyme.

**f) Mode of action of fumigants**

Fumigants are the narcotics inducing narcosis, unconsciousness and finally death. Their mode of action is rather physical than chemical. They are fat soluble and lodge in fatty tissues, including nerve sheath and lipoproteins of the brain. Their activity is altered very little by structural changes in their molecules.

**g) Mode of action of rotenone**

The symptoms of poisoning in insects are inactivity, locomotion instability, refusal to eat, knockdown, paralysis and slow death. It is a respiratory enzyme inhibitor, acting between  $NAD^+$  and coenzyme Q, due to which the respiratory functions become failure. Rotenone poisoned insects exhibits steady decline in oxygen consumption. Inhibitory potency of rotenone is due to its ability to interfere with the electron transport process between reduced diphosphopyridine nucleotide and cytochrome b. Thus blockage of nerve conduction is due to the inhibition of respiratory metabolism.

**h) Mode of action of chitin synthesis inhibitors**

Ex : Benzophenyl ureas (Diﬂubenzuron) and Buprofezin

These compounds inhibit chitin formation there by causing abnormal endo cuticular deposition and abortive molting. These compound alter cuticle composition of cuticle especially chitin there by affecting the elasticity and firmness of the endo cuticle. The reduced level of chitin in the cuticle is due to the inhibition of enzyme, chitin synthetase.

**i) Mode of action of neem extract**

Neem extract contains several active ingredients. Azadirachtin is one of the major constituent exhibiting about 90% of the neem extract. Azadirachtin structurally similar to the insect molting hormone ecdysone, interacts with the corpus cardiacum, thereby blocking the activity of the molting hormone. It acts as an insect growth regulator suppressing fecundity, molting, pupation and adult formation. Other constituents showing high potency on insects structurally related to azadirachtin are the salanin, melianol and nimbin.

**j) Mode of action of muscle poisons**

Ex : Rynia and sabadilla

Muscle poisons have a direct influence on muscle tissues. The alkaloid disrupts the excitable membrane of muscle. This disruption results in up to a ten fold increase in oxygen consumption, followed by flaccid paralysis and death.

**k) Mode of action of avermectins**

Avermectins are a group of macrocyclic lactones isolated from fermentation of the soil microorganisms, *Streptomyces avermitilis* Burg. These compounds act as agonists for gamma amino butyric acid (GABA) gated chloride channels. They bind with high affinity to sites in the head and muscle neuronal membranes of various insect species. Avermectins bind to a common site in all gated chloride channels.

**Mode of action of insecticides**

| S.No | Main group and primary site of action    | Chemical sub - group                                                      | Active ingredients                                                                                                    |
|------|------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| 1    | Acetyl choline esterase inhibitors       | Organophosphates                                                          | Profenophos, Quinalphos, Triazophos                                                                                   |
| 2    | GABA- gated chloride channel antagonists | Carbamates<br>Cyclodiene<br>organochlorines<br>Phenylpyrazoles (Fiproles) | Carbaryl, Carbosulfan<br>Endosulfan<br>Fipronil                                                                       |
| 3    | Sodium channel modulators                | Pyrethroids<br>DDT                                                        | Fipronil, Bifenthrin, Beta-cyfluthrin<br>Lambda - cyhalothrin, Cypermethrin, Alpha-methrin, Deltamethrin, Fenvalerate |

|   |                                                        |                |                                |
|---|--------------------------------------------------------|----------------|--------------------------------|
| 4 | Nicotinic acetylcholine receptor agonists              | Neonicotinoids | Acetamiprid, Imidacloprid      |
| 5 | Nicotinic acetylcholine receptor allosteric activators | Spinosyns      | Spinosad                       |
| 6 | Chloride channel activators                            | Avermectins    | Abamectin, Emamectin benzoate, |
| 7 | Ecdysone agonists / moulting                           | Azadirachtin   | Neem commercial formulations   |
| 8 | Voltage - dependent sodium channel blockers            | Indoxacarb     | Indoxacarb                     |

### 6.13 METABOLISM OF INSECTICIDES

When an insecticides is applied on any organism it undergoes some chemical changes resulting in the formation of new products called metabolites and the process is known as metabolism.

The metabolism of organic insecticides can be divided into two

1. Activation
2. Detoxification

- 1. Activation** : The metabolic reaction that converts an inactive compound to an active compound or an active compound to another active compound or compounds.
- 2. Detoxification** : The metabolic reaction that converts the compound in to non toxic compounds.

Enzymes involved in metabolism are esterases and mixed function oxidases

Metabolic pathways are two types

- I. Phase I reactions
- II. Phase II reactions

#### Phase I reactions

- i). **Oxidation** : This class includes all those enzymes in which one atom of a molecule of oxygen is reduced to water while the other is used to oxidize the substrate. This takes place by mixed function oxidases.
- ii). **Reduction** : In these reactions halogen is replaced by hydrogen atom.
- iii). **Hydrolytic processes** : These takes place by esterases. The positivity of phosphorus

atom of insecticides is reduced. Three types of esterase are found in plants and animals namely phosphatases, carboxyesterases and carboxyamidases.

- iv). **Glutathione mediated reaction** : In this reactions glutathione is utilized either in a purely catalytic manner or consumed by the direct binding to the substrate.

### Phase II reactions

In these reactions insecticides are metabolized by conjugation reactions

- i). **Glutathione conjugation** : In these reactions the harmful electrophilic compounds are conjugated with GSH (reduced glutathione) and with this the other nucleophilic centres such as proteins and nucleic acids are protected.
- ii). **Glucoside conjugation** : In these reactions the harmful xenobiotics or their metabolites combine with glucose to form conjugates.
- iii). **Amino acid conjugation** : It occurs by the activation of the xenobiotic acid through the enzyme requiring ATP and followed by condensation with endogenous amino acid

### Metabolism of insecticides

#### I. Metabolism of chlorinated hydrocarbons

##### 1. Metabolism of DDT

DDT  $\xrightarrow{\text{rats and man}}$  Dichloro diphenyl acetic acid (DDA)

DDT  $\xrightarrow{\text{Drosophila}}$  Dicofol

DDT  $\xrightarrow{\text{Cockroaches and fruit fly larvae}}$  Dichloro benzophenone (DBP)

DDT  $\xrightarrow{\text{plants}}$  Dichloro diphenyl dichloro ethane (DDD)

DDT  $\xrightarrow{\text{in resistant insects}}$  Dichloro diphenyl dichloro ethylene (DDE)

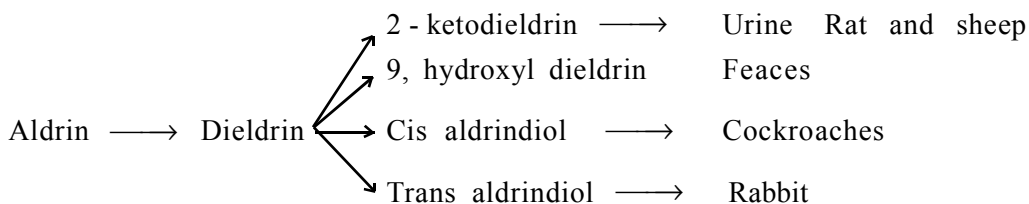
##### 2. Metabolism of Lindane

Lindane metabolism in mammals

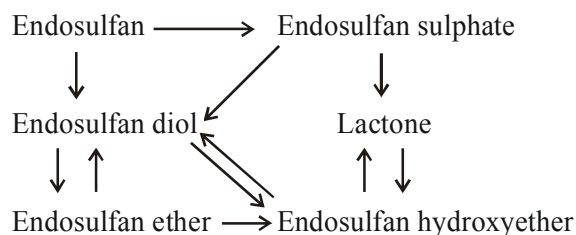
Lindane  $\longrightarrow$  pentachloro cyclohexane  $\longrightarrow$  1,2,4 trichloro benzene  $\longrightarrow$  phenols  $\longrightarrow$  sulphates  $\longrightarrow$  glucuronic acid conjugates  $\longrightarrow$  excreted in urine



### 3. Metabolism of Aldrin

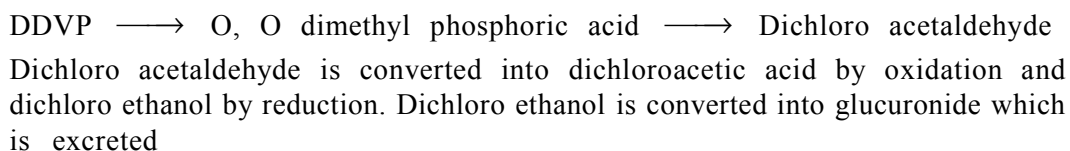


### 4. Metabolism of Endosulfan

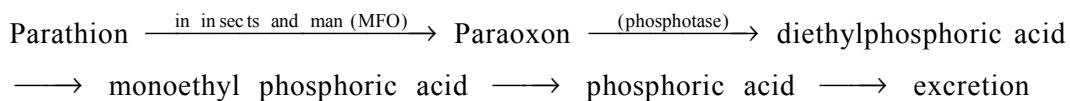


## II. Metabolism of organophosphates

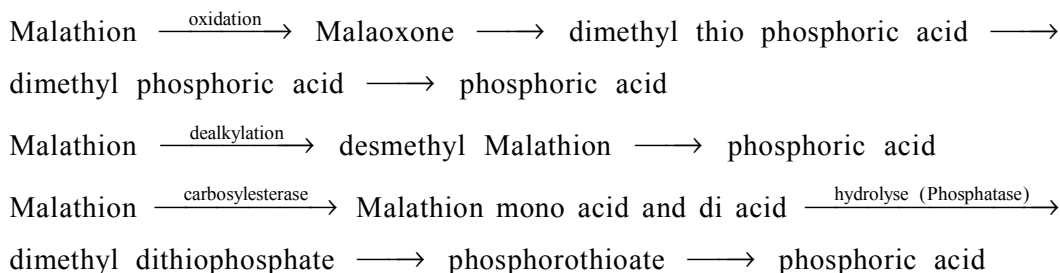
### 1. Metabolism of DDVP



### 2. Metabolism of Parathion



### 3. Metabolism of Malathion



Malthion  $\xrightarrow{\text{Aspergillus}}$  desmethyl malathion

#### 4. Metabolism of Dimethoate

Dimethoate  $\xrightarrow{(\text{Carboxyamidase})}$  dimethionate acid

Dimethoate  $\xrightarrow{(\text{hydrolysis})}$  phosphoric acid derivatives

#### 5. Metabolism of Phorate

Phorate  $\longrightarrow$  sulfoxide and sulfone  $\xrightarrow{(\text{Phosphatase})}$  phosphoric acid and sulfone derivative of thio alcohol

### III. Metabolism of carbamates

#### 1. Metabolism of Carbaryl

Carbaryl  $\xrightarrow{\text{hydrolysed}}$  Napthol + CO<sub>2</sub> + methylamine

#### 2. Metabolism of Carbofuran

Carbofuran  $\xrightarrow{\text{oxidation}}$  3 - hydroxy carbofuran + 3-keto carbofuran

#### 3. Metabolism of Aldicarb

Aldicarb  $\longrightarrow$  aldicarb sulfoxide  $\longrightarrow$  oxime sulfoxide  $\longrightarrow$  excreted

#### 4. Metabolism of Nicotine

Nicotine is metabolized to cotinine in plants, animals and man

Nicotine  $\longrightarrow$  2, hydroxyl nicotine  $\longrightarrow$  cotinine  $\longrightarrow$  desmethyl cotinine

### IV. Metabolism of cypermethrin

It involves a wide range of pathways, with the primary pathway being cleavage of the ester bond. Cypermethrin is primarily a mixture of *cis* and *trans* isomers, with a *cis* configuration greatly reducing the cleavage rate. Therefore, *cis* - cypermethrin is more metabolically stable, but is still efficiently metabolized for rapid excretion. The major metabolites formed are 3 - phenoxybenzoic acid (PBA) and 4' - hydroxy - 3 - phenoxybenzoic acid. It is much more toxic to insects than mammals because the insect metabolism rate is much slower.

In mammals and birds, cypermethrin is relatively non - toxic. Studies have shown that, when ingested, they excrete cypermethrin, posing a low toxicological threat to them. Because of its high lipoaffinity and low solubility, cypermethrin has a strong potential to bio - accumulate in aquatic hence highly toxic to aquatic organisms

and fish.

In plants, the primary metabolic reaction is ester cleavage which produces a - cyano - phenoxybenzyl alcohol. It is not toxic to the plants, but is toxic to the insects which feed on them. Eventually, cypermethrin will metabolize to conjugates mono and disaccharide derivatives.

## 6.14 INSECTICIDE RESISTANCE

### **Insecticide resistance**

The development of an ability in a strain of insects to tolerate doses of toxicant which would prove lethal to majority of the individuals in a normal population of the same species.

### **Types of resistance**

- a) **Simple resistance** : Resistance is limited to only one insecticide and not to the related ones.
- b) **Cross resistance** : An insect resistant to one insecticide is also resistant to the related ones.
- c) **Multiple resistance** : The co-existence of different defence mechanisms in the same strain.
- d) **Monogenic resistance** : Single gene is involved in the development of resistance.
- e) **Polygenic resistance** : Several genes are involved in the development of resistance.

The rate of development of resistance in a population depends on 4 factors

1. The frequency of resistant genes present in a population
2. The nature of genes (single or multiple; dominant or recessive)
3. The intensity of the selection pressure of the toxicant
4. The rate of breeding of the species

### **Mechanisms of resistance**

There are 3 mechanisms of resistance

1. Pre - adaptive (genetic) mechanism
2. Physiological mechanism
3. Behaviour and ecological mechanism

### 1. Pre adaptive (genetic)

- In house fly, the resistance to DDT is due to the recessive gene called kdr (knock down resistance) on chromosome 3
- In resistance house flies, DDT detoxification takes place by an enzyme, DDTase located on chromosome 5
- Dominant R factor found on chromosome-2 in *Drosophila melanogaster* is responsible for DDT and BHC resistance

### 2. Physiological mechanism

- a) **Detoxification** : Resistance to insecticides is due to the ability of the insect to detoxify them by detoxifying enzymes such as carboxyesterases and glutathione S transferase. These enzymes are present in large quantities in R (resistant) strains and low or absent in S (susceptible) strains. These enzymes are synthesized by microsomes.

Ex : Dehydrochlorinase detoxifies DDT into non toxic DDE in DDT resistant house flies

- b) **Cuticular penetration** : In R strains the insecticide penetrate the cuticle more slowly than in S strain.
- c) **Penetration into target organs** : The penetration of toxicant to target organs like nervous tissues (ganglia) is less in R strains therefore less sensitive to toxicant than that in S strains.
- d) **Increased storage** : The ability of storing insecticide in the non sensitive tissue like fat body is more in R strains than in S strains. It also differs between males and females of the same species.
- e) **Decreased sensitivity of tissues** : Nervous tissues of R strains is less sensitive to toxicants because of poor permeability of the covering sheath and neural lamella than that of S strains.
- f) **Excretion of toxicant** : The rate of production of metabolite is same in both the strains, but excretion of metabolite is very fast in resistant strains than in susceptible strain.
- g) **Dietary factors** : The larvae of tobacco bud worm show resistance against DDT when their diet contains high level of ascorbic acid and lipids
- h) **Fat body insulation** : In R strains of house flies the total fat body content is more than that in S strains. The lipid tissue keeps the toxicant away from the sensitive sites and acts as insulation against insecticides.

### 3. Behaviour and ecological mechanism

Behaviour resistance is defined as the ability of insect through protective habits or behaviour to avoid lethal contact with a toxicant.

- a) **Avoidance of treated surface:** DDT causes irritability to Anopheline mosquitoes with the result that the mosquitoes avoid the treated surface. Codling moth due to its acquired habit, rejects the first bite prior to penetration in the fruit.
- b) **Decreased period of contact:** In R strains the irritability of tissues on contact with insecticides is greater. This makes the insect fly away, leading to a reduced period of contact with the insecticides and thus lesser harm due to the toxicant.

## 6.15 MANAGEMENT OF INSECTICIDES RESISTANCE

### Insecticide resistance management (IRM)

The strategies used to delay the onset of resistance to manage resistant populations are known as insecticide resistance management (IRM).

#### Steps to manage insecticide resistance are

1. Judicious use of insecticides
  2. Insecticide rotation
  3. Use of undetoxifiable analogues
  4. Use of synergists
  5. Mixture and alternation of insecticides
  6. Negatively correlated insecticides
  7. Development of newer insecticides
  8. Use of insect pheromone and hormones
  9. Use of integrated approach
1. **Judicious use of insecticides:** Indiscriminate use of insecticides lead to the development of resistance. Need based insecticidal spray should be taken up when the pest population reaches economic threshold level. Selective insecticides should be sprayed using proper dose and right equipment.
  2. **Insecticide rotation:** Same insecticide should not used for a long time. Insects resistant to one insecticide may not be resistant to another. Change of insecticide prevents the development of resistance.
  3. **Use of undetoxifiable analogues:** DDT analogues such as Dilan (mixture of prolan and bulan) are not easily detoxified by the DDT resistant strains. The carbomethoxy analog of malathion can not be detoxified by malathion resistant strains and be used successfully against them.
  4. **Use of synergists:** Synergists enhance the toxicity of the insecticides by blocking

their detoxification enzymes. Resistance to organophosphates, carbamates and pyrethrum is overcome by addition of synergists such as piperonyl butoxide. Malathion resistance is overcome by use of synergists such as triphenyl phosphate and tributyl phosphorotrithioate.

5. **Mixture and alternation of insecticides :** A mixture of two insecticides with independent action against the resistant strain give good control and delays the development of resistance. Since whiteflies developed resistance against synthetic pyrethroids on cotton, mixture of cypermethrin and profenfos is used to overcome the problem. Alternation of insecticides with each generation of the insect delays the development of resistance.
6. **Negatively correlated insecticides :** Specific resistance to one insecticide carries an enhanced susceptibility to another insecticide, the cross resistance characteristics of the two insecticides become negatively correlated and this each constitutes a counter measure for resistance to the other.
7. **Development of newer insecticides :** Switching over to newly evolved insecticides or to microbial insecticides is an important counter measure for delaying the resistance.
8. **Use of insect pheromone and hormones :** Pheromones modulate the insect behaviour and hormones regulate growth and reproduction of insects. These can be used successfully against resistance strains.
9. **Use of integrated approach :** Use of Integrated pest management (IPM) practices reduce the application of insecticides which in turn lower the insecticide pressure on insects. Genes governing resistance may not get activated and hence the development of resistance is delayed.

### 6.16 Grain Protectants

- A grain protectant may be added to the grain when the bin is being filled to guard against insect damage
- Protectants may also be added to the upper surface of the grain in the bin (top dressing) to protect against damage from moths and other insects entering the top of the storage facility
- Protectants are recommended if grain is going to be stored for extended periods
- Protectants will not eliminate existing infestations and should only be applied to clean, dry grain
- The combination of high grain moisture and high temperatures will shorten the residual life of grain protectants

**Examples**

1. **Reldan** 4E (Chlorpyrifos-methyl) is labeled for use on barley, oats, rice, grain sorghum and wheat but is not labeled on corn. Reldan does not have activity on lesser grain borer and has limited activity on existing populations of insects.
2. **Storcide** II (Chlorpyrifos-methyl + deltamethrin) is registered for use on barley, oats, rice, sorghum and wheat. It is replacement for Reldan and Storcide. It is effective against a broad spectrum of stored grain pests, including lesser grain borer.
3. **Diacon** II [(s)-methoprene] (IGR) is registered for use on corn, barley, oats, rice, peanuts, grain sorghum, peanuts, sunflowers, wheat and all food commodities.
4. **Acetellic** 5E (Pirimiphos-methyl) is registered for use on corn and grain sorghum.
5. **Silicon dioxide** and/or diatomaceous earth (DE) (Insecto, Perma-Guard, Protect-It) are registered for all grains. Applications of these materials to the entire grain mass can lower test weight and reduce the flowability of the grain. In many cases, these products are only applied to the bottom and top layers of the grain.
6. **Bacillus thuringiensis** (Bt) (Dipel, Biobit) is registered for use on all grains including soybeans.
7. **Pyrethrins** + piperonyl butoxide is labeled on corn, wheat, rye, oats, barley, and grain sorghum.
8. 6% **Malathion** Grain Dust is labeled for application to wheat, corn, oats, rye, and barley. Only the dust formulation is labeled for direct grain applications! Due to resistance problems with this active ingredient and concerns over residues in flour, malathion is not suggested for direct applications to stored products.

**Empty-bin Sprays**

Empty-bin sprays are recommended when grain is stored in the summer, if there are difficult to clean areas or if there has been a history of insect problems. After bins have been properly cleaned and inspected and prior to adding new grain, treat the empty bin with a labeled insecticide. Spray to run-off the inside surface and as much of the outside, including the nearby ground surfaces, aeration ducts, and grain handling equipment, as possible. Sprays should be concentrated on cracks, crevices, and hard to clean areas. Applications should be made at least two weeks prior to adding new grain. Allow 24 hours for sprays to dry. These sprays provide a barrier to insects that may be attracted to the storage facilities and also provide control of the insects not removed during the cleaning operation.

**Examples**

Storcide II (chlorpyrifos-methyl + deltamethrin), Storcide (chlorpyrifos-methyl + cyfluthrin), Tempo (cyfluthrin), Malathion, Reldan 4E (chlorpyrifos-methyl), Diacon II [(s)-methoprene], Silicon dioxide and/or diatomaceous earth (DE) (Insecto, Perma-Guard), and *Bacillus thuringiensis* (Bt) (Dipel, Biobit), are all labeled as empty-bin sprays.

Tempo (Cyfluthrin) is registered for use in crack and crevices and on empty bin sprays, but it is not registered for use on commodities.

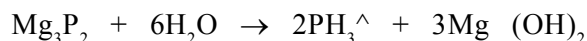
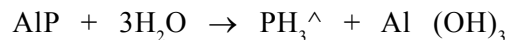
**6.17 Fumigants****Methyl bromide**

Methyl bromide also known as monobromomethane. The insecticidal value of methyl bromide was first reported by Le Goupil (1932) in France. Its ability to penetrate quickly and deeply into sorptive materials at normal atmospheric pressure makes methyl bromide an effective and versatile fumigant. Also, at the end of a treatment, the vapours dissipate rapidly and make possible the safe handling of bulk commodities. Another important property is the fact that many living plants are tolerant to this gas in insecticidal treatments. Methyl bromide is nonflammable and non-explosive under ordinary circumstances and may be used without special precautions against fire.

Because methyl bromide has a comparatively low boiling point and is not greatly sorbed by many materials, it may be used for low temperature treatments that are not practicable with many other fumigants.

**Phosphine**

Phosphine or hydrogen phosphide ( $\text{PH}_3$ ) is a low molecular weight, low boiling point compound that diffuses rapidly and penetrates deeply into materials, such as large bulks of grain or tightly packed materials. The gas is produced from formulations of metallic phosphides (usually aluminium or magnesium phosphide) that contain additional materials for regulating release of the gas.



Aluminium phosphide is formulated as tablets, pellets or small sachets of powder with additional materials such as ammonium carbamate, ammonium bicarbonate, urea



and paraffin to regulate release of fumigant and suppress flammability. The formulation is embedded in a plastic matrix that regulates access of moisture and hence controls release of the gas. After the phosphine has evolved from a formulation, the residue that remains consists mainly of aluminium or magnesium hydroxide. Small amounts of un-decomposed aluminium phosphide may also remain in the grey-white dust from tablets, pellets or sachets.

A strong odour, resembling carbide or garlic, is normally associated with the evolution of phosphine from various formulations.

Phosphine is very toxic to all forms of animal life, hence exposure of human beings even to small amounts should be avoided. Phosphine ranks as one of the most toxic fumigants of stored product insects. It is a slow acting poison that is effective at very low concentrations if the exposure time is long enough. Usually, exposure times of four or more days are required to control insects, depending on temperature. The toxicity of phosphine to insects declines as the temperature falls to 5°C, so that longer exposure times are required for it to exert its effect. It is not recommended for use below 5°C. The exposure time cannot be shortened by increasing the dosage; in fact, high concentrations can have a narcotic effect on insects thereby reducing mortality.

Phosphine has an inhibitory effect on insect respiration and is unique in that it is only toxic to insects in the presence of oxygen - in the absence of oxygen it is not absorbed and is not toxic to insects. However, the action of phosphine is potentiated by carbon dioxide and the exposure time can be reduced when both gases are present.

Some stages of insects are considerably more tolerant to phosphine than others. The eggs and pupae are usually hardest to kill while larvae and adults succumb more easily.

Phosphine in insecticidal treatments does not, under normal conditions, affect the germination of seeds.

The residues resulting from the use of phosphine fumigants may be of three types: reaction products of the formulation, unchanged phosphine absorbed in commodity or products formed by chemical combination of phosphine with components of the commodity.

Formulations of aluminium or magnesium phosphide leave mainly an inert residue of the metallic hydroxide. In formulations of aluminium phosphide, a small amount of unreacted material may also remain, and hence some precautions should be taken to avoid hazards from the unspent formulation.

### Hydrogen cyanide (HCN)

Hydrogen cyanide or hydrocyanic acid (HCN) was one of the first fumigants to be used extensively under modern conditions. Its use for treating trees under tents against scale insects was developed in California in 1886. The use of HCN has been declining in recent years, but it is still important in certain fields of application.

HCN is one of the most toxic of insect fumigants. The fact that it is very soluble in water has considerable bearing on its use in practice. Thus, it may produce injury on moist materials, such as fruit and vegetables, because the solution of HCN in water is a dilute acid. Not only does this acid render these materials unpalatable and possibly hazardous for human consumption, but its action, by causing burning, wilting or discoloration, may make them unmarketable.

On the other hand, HCN has been widely used for fumigating dormant nursery stock that is sufficiently dry. It may be used for some living plants if they can be washed with water immediately after treatment to prevent burning by the acid.

HCN may be employed for fumigating many dry foodstuffs, grains and seeds. Although HCN is strongly sorbed by many materials, this action is usually reversible when they are dry, and, given time, all the fumigant vapours are desorbed. With many foodstuffs little, if any, chemical reaction occurs, and there is no detectable permanent residue.

Because of the high degree of sorption at atmospheric pressure, HCN does not penetrate well into some materials. It was largely because of this that vacuum fumigation was adopted.

Among the commonly used fumigants, HCN is one of the most toxic to insects. It also has a rapid paralyzing effect on most species. This action is an important consideration in dealing with insects, because sub-lethal concentrations may bring about apparent death. After exposure to the fumigant, the reversible action of the poison may permit the insect to recover. This reaction has already been referred to as protective stupefaction. It is important from the practical point of view because it means that the maximum recommended concentration should be attained as quickly as possible during the application of the fumigant.

HCN applied in dosages effective against insects does not affect the viability of seeds that are normally dry, with moisture contents suitable for storage.

### Ethylene dibromide

The insecticidal properties of ethylene dibromide (EDB) or **1, 2-dibromoethane, ethylene bromide** were reported by Neifert et al in 1925. EDB is highly insecticidal, and under normal conditions the residues remaining in foodstuffs are of a low order. These advantages are offset by the fact that EDB is considered to be

very hazardous to mammals and is highly sorbed by materials undergoing fumigation. As a result, there may be poor penetration during actual treatment and prolonged persistence of the vapours in the fumigated commodity during the aeration process. Attempts to utilize the advantages and overcome the disadvantages have resulted in the formulation of a wide variety of mixtures.

EDB has no effect on the germination. It is more toxic to human beings than methyl bromide. EDB has been known to cause for its carcinogenic effects.

### **Carbon disulphide**

Carbon disulphide ( $\text{CS}_2$ ) was one of the first fumigants employed on a large scale. Its use in France, in 1869, against the grape phylloxera is a landmark in the history of applied entomology. It was injected into the soil to control the insects infesting the roots of the grapevine. For many years afterwards,  $\text{CS}_2$  was widely used as a soil or space fumigant. Its tendency to burn or explode presents a hazard, and many explosions have been recorded during its use as a fumigant.

Carbon disulphide penetrates well and is still the only fumigant used in certain parts of the world. It is of practical value in tropical countries where the high temperatures favour volatilization.

Carbon disulphide is commonly formulated in mixtures with nonflammable ingredients for fumigating grain.  $\text{CS}_2$  ranks rather low among the insect fumigants because relatively large dosages by weight are required.

### **Chloropicrin**

Chloropicrin or **trichloronitromethane or nitrochloroform** is a powerful tear gas; it is one of the most toxic to insects. It is sometimes added in small proportions to other fumigants, e.g., hydrogen cyanide and methyl bromide, to serve as a warning agent.

Although the tear gas effect of Chloropicrin is helpful in preventing persons from staying in dangerous concentrations during the fumigation process, it is also a handicap because fumigated commodities are unpleasant to handle for some time after fumigation. Even comparatively small amounts diffusing from the treated material may be extremely irritating. If it were not for this disadvantage, Chloropicrin would be useful for commodity treatments as it penetrates effectively into many materials.

Chloropicrin is also toxic to nematodes and certain fungi and it has found wide application as a soil fumigant.

Chloropicrin is corrosive to metals and care should be taken to protect metal surfaces and equipment during treatment.

Chloropicrin is extremely phytotoxic and plants exposed to its vapours are often completely destroyed. Nevertheless, it is possible to fumigate certain seeds with concentrations of chloropicrin toxic to insects without impairing germination.

Chloropicrin should not be used for the fumigation of fresh fruit or vegetables. It may be used on bagged or packaged plant products at atmospheric pressure if ample time is allowed for post fumigation aeration. The irritating vapours must be allowed to diffuse before the material is handled or consumed.

If chloropicrin is present in fumigated flour, it may have a bad effect on the baking quality, but this effect disappears once the material is fully aerated.

### **Sulphuryl fluoride**

Sulphuryl fluoride has been developed as an effective fumigant for controlling dry wood termites. This gas has outstanding dispersion and penetrating qualities which permit it to infiltrate termite tunnels and crevices and destroy the insects. Sulphuryl fluoride does not escape through plastic sheets used in structural fumigation as rapidly as methyl bromide or other organic fumigants. Because this gas is odourless, chloropicrin, discharged separately, is recommended as a warning agent.

Sulphuryl fluoride is generally very toxic to all postembryonic stages of insects, but the eggs of many species are extremely resistant. It has been suggested that this resistance is largely due to the impenetrable nature of the eggshell layers to this chemical.

Sulphuryl fluoride has little or no effect on the germination of weed and crop seeds; however, it is injurious to green plants, vegetables, fruits and tubers. Sulphuryl fluoride is sorbed less than methyl bromide in wheat, wood flour and many other materials.”

Under no conditions should sulphuryl fluoride be used on raw agricultural food commodities, or on foods, feeds or medicines destined for human or animal consumption. Do not use on living plants

### **Ethylene dichloride**

Compared with most modern fumigants, ethylene dichloride (EDC) is intrinsically not very toxic to insects but its mixture with CT, usually in the proportion by volume of 3 : 1 EDC to CT, has been used throughout the world as a successful fumigant for stored grain in a variety of structures. It has proved effective under tropical conditions in Africa (Hall, 1963). Its use for this purpose is contingent on a long exposure period, usually not less than 14 days, before the grain is turned or the fumigant aerated (Thompson, 1964). Such long exposure periods do not appear to have adverse effects on the grain. It may be applied either by gravity distribution

or forced distribution systems.

This mixture has also been widely used as a seed fumigant. Properly used it does not have an adverse effect on the germination of seeds.

### **Vacuum fumigation**

In vacuum fumigation, most of the air in the chamber is removed before the fumigant is introduced. It is, therefore, necessary to have a specially constructed chamber, usually made of steel, that is capable of withstanding external pressure up to one atmosphere.

The primary object of vacuum fumigation is to hasten and improve the penetration of the fumigant into the material undergoing treatment.

The fact that a vacuum treatment may be completed in 1.5 to 4 hours, as opposed to 12 to 24 hours for atmospheric fumigation, may commend it for use when a quick turnover of goods is necessary.

It was originally developed for this purpose when hydrogen cyanide (HCN) was the principal fumigant used.

Today, the technique is used chiefly in plant quarantine work and in materials which are difficult to penetrate at atmospheric pressure. It is also used in some food manufacturing industries for the fumigation of packaged cereals and prepared foods.

Vacuum fumigation cannot be used with certain tender plants, fruits and vegetables which are unable to withstand reduced pressure.

A vacuum fumigation installation is considerably more expensive than an atmospheric chamber of the same capacity. The decision as to whether the vacuum technique should be adopted should be made by weighing the possible advantages against the greater cost of installation.

## **6.18 Role of Nanotechnology in IPM**

### **Introduction**

The word “Nano” is developed from the Greek word meaning “dwarf”. In more technical terms, the word “nano” means  $10^{-9}$ , or one billionth of something. The word nanotechnology evolved due to use of nanometer size particles (size of 1 to 100 nm). Nanotechnology exhibits the top down phenomena, which means reducing the size of the smallest structures to the nano-scale. It is bottom up approach, involving individual atom by atom and molecules into nanostructures, which are applicable in several biological processes. Thus, nanotechnology deals with the

targeted nanoparticles as and when the particles exhibit different physical strength, chemical reactivity, electrical conductance and magnetic properties.

### Natural occurrence of nano-particles in insects

Several insects possess ferromagnetic materials in their body divisions i.e., head, thorax and abdomen. These materials act as geomagnetic sensors. The arrangement of nano-particles in atom-by-atom pattern allows them by influencing their shape, size and orientation to react with the targeted tissues. An array of structures in hexagonal ordered form is present in the wings of cicada and in the termites of the family Rhinotermitidae. The nano-particles in the insect wings help to increase the aerodynamic effectiveness of the insect. Similarly, the insects have temperature dependent ferromagnetic resonance. In the head, thorax and abdomen of the insects like ants, the magnetic material is present. In social insects, geomagnetic sensors are these magnetic nano-particles. Geomagnetic field information is used by the honey bees for homing, foraging and orientation. The ants, *Formica rufa* and *Solenopsis invicta* also uses geomagnetic field for orientation and foraging. Electron microscope technique observations demonstrate that many ant species use magnetite nano-particles to recognize the magnetic signals. Ferric iron has also been observed in the abdomen of *S. invicta* workers. Magnetic particles have also been observed in the in the stingless bees. Magnetic resonance imaging (MRI) technique was used to detect natural magnetism in fire ant (*S. invicta*) queens, workers and alates. Bright colour components of butterflies and compound eyes of insects contain nano-particles.

### Nano technology in IPM

The potential uses and benefits of nanotechnology are enormous. These include management of insect pests through the formulations of nanomaterials-based insecticides. Traditional strategies like integrated pest management used in agriculture are insufficient, and application of chemical pesticides have adverse effects on animals and human beings. Therefore, nanotechnology would provide green and efficient alternatives for the management of insect pests in agriculture without harming the nature.

Nanopesticides encompass a great variety of products and cannot be considered as a single category. Nanopesticides can consist of organic ingredients (e.g., a.i., polymers) and/or inorganic ingredients (e.g., metal oxides) in various forms (e.g., particles and micelles). The aims of nano-formulations are generally common to pesticide formulations and consist in:

1. Increasing the apparent solubility of poorly soluble active ingredient
2. Releasing the active ingredient in a slow/targeted manner and/or protecting the active

ingredient against premature degradation

Nanopesticide are small engineered structure which provides pesticidal properties or formulation of active ingredient of pesticide in nanoform. These nano structures have slow degradation and controlled release of active ingredient for long time. Nanopesticides can increase the dispersion and wettability of agricultural formulations, and unwanted pesticide movement. These possess properties such as stiffness, permeability, crystallinity, thermal stability, solubility and biodegradability. These also offer large specific surface area and hence, increased affinity to the target. These properties of nanopesticide make them environmentally safe and less toxic in comparison to chemical pesticide. There are different types of nanopesticide such as nanocapsulated formulations, nanoemulsion, nanogel, nanospheres, and metal and metal oxide nanoparticles.

### **Nanoencapsulation**

Nano-encapsulation, a good example of nanotechnology that is recently being applies as new technology for host plant's protection against insect pests. Nano-encapsulation is a process through which a chemical such as an insecticide is slowly but efficiently released to a particular host plant for insect pest control. Here the pesticide or the chemical compound is encapsulated inside on an artificially synthesized nano-matrix. This nano-matrix coat facilitates the release of the pesticide only in the targeted environment like in specific pH condition, specific temperature or in the presence of specific compounds. Nano-encapsulation with nano-particles in form of pesticides allows for proper absorption of the chemical into the plants unlike the case of larger particles. Some encapsulation is done in such way that it gets absorbed in the surface of the plant and facilitates prolong release which lasts for longer time. Release mechanisms include dissolution, biodegradation, diffusion and osmotic pressure with specific pH.

Nanoencapsulation of the pesticide is done to minimize the doses and to get maximum effect with more target oriented action of the pesticides. For example the pesticide will release in the intestine, as the synthesized nano matrix will dissolved in the environmental condition of the intestine of that specific insects, and will kill the targeted insects only. Encapsulated citronella oil nano-emulsion is prepared by high-pressure homogenization of 2.5% surfactant and 100% glycerol, to create stable droplets that increase the retention of the oil and slow release. The release rate depends upon the protection time; consequently a decrease in release rate can prolong mosquito protection time.

### **Nanoemulsions**

Nanoemulsions (NEs) were developed to improve solubility and spreading capacity



of pesticide by dispersion into two liquid phases. They have better kinetic stability, smaller size, low viscosity and optical transparency, which can potentially be better pesticide delivery medium. The micro or nanoemulsion as a carrier for pesticide delivery can improve the solubility and bioavailability of nanopesticides. They have greater spreadability, wettability, and superior mechanical stability in comparison to normal emulsion. These characteristic of NEs found helpful in less degradation and volatilization of active ingredient (AI) and improve their bioavailability for long time period. Surfactant based nano-emulsions of beta-cypermethrin, nanoemulsion of permethrin and nanoemulsion of neem oil were developed. Nanoemulsion of different fatty acid methyl esters, organosilicones, alkyl glucosides and Tebuconazole (TBZ) were formulated to improve their efficacy against different insect pests. Nano-emulsions (oil in water) were considered as useful for pesticide formulations and efficient against several agricultural insect pests.

### **Nanoparticles**

Nano-particles help to produce new pesticides, insecticides and insect repellents. This process can also deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests. Nanoparticles association with insecticide increased their activity many folds by providing more loading capacity and controlled release patterns. Chlorfenapyr associated with silica nanoparticles showed twice insecticidal activity in laboratory and field tests. Silica nanoparticles coated with 3 mercapto- propyl-triethoxy-silane were found more efficient against insects.

### **Nano-silica**

Nano-silica that is prepared from silica can also be used as nano-pesticide. Insects use a diversity of lipids on their cuticle for the protection of water obstruction on their bodies thus preventing the death from dryness. This mechanism of insect protection is used by the nano-silica that becomes absorbed into the lipids of cuticle by physiosorption thus causing insect death solely by physical ways when this pesticide is applied on the surfaces of leaves and stem. Surface charged, modified, hydrophobic nano-silica can be successfully used to control a range of agricultural insect pests and animal ectoparasites of veterinary importance.

A wide range of agricultural insect pests can be controlled by the use of nano-silica. Sprays of nano-silica on tomato plants influence the feeding preference of *Spodoptera littoralis* ultimately increasing the resistance in plants. It affects the reproductive potential of insect females causing a reduction in population density of insect and increases the yield.



**Metal and metal oxide nano-particles**

Different type of metal or their oxide were also explored in development of inorganic nanoparticle for insecticidal applications. Different types of nano particles like aluminium oxide nano particles (ANP), silver nano particles (SNP), titanium dioxide and zinc oxide were used for the control of grasserie disease in silkworm and rice weevil. Alumina nanoparticles were exhibited grater mortality against different pests like *Sitophilus oryzae* and *Rhyzopertha dominica*. The pediculocidal and larvicidal activity of synthesized silver nanoparticles using an aqueous leaf extract of *Tinospora cordifolia* showed maximum mortality against the head louse *Pediculus humanus* and fourth instar larvae of *Anopheles subpictus* and *Culex quinquefasciatus*.

**Nano capsules**

Nanocapsules have shown controlled release and slow degradation properties of active ingredient (AI), making them more efficient in controlling plant diseases and insect pests. Different type of polysaccharide materials have been incorporated in synthesis i.e chitosan, poly ethylene glycol (PEG), starch, cellulose and polyester substance. Temephos and imidacloprid containing PEG encapsulated nanopesticide are more active against larvae of *Culex quinquefasciatus*.

Similarly, PEG nanoparticles with essential oil (EO) extracted from *Geranium* sp. and *Citrus reticulata* are effective against *Blatella germanica*. Essential oil containing PEG nanoparticles showed slow release of terpenes that enhanced the toxicity multifold to insect *B. germanica*. Nano-particles coated with polyethylene glycol that were coated with natural oil of garlic were effective against red flour beetle, *Tribolium castaneum*.

**Nanogel**

Environment-friendly management of fruit flies involving pheromones is useful in reducing the undesirable pest populations responsible for decreasing the yield and the crop quality. A nanogel has been prepared from a pheromone, methyl eugenol (ME) using a low-molecular mass gelator. This was very stable at open ambient conditions and slowed down the evaporation of pheromone significantly. This enabled its easy handling and transportation without refrigeration, and reduction in them frequency of pheromone recharging in the orchard. Notably the involvement of the nanogelled pheromone brought about an effective management of oriental fruit fly, *Bactrocera dorsalis*, a prevalent harmful pest for a number of fruits including guava.

**Nanotube**

Nanotube filled with alumina-silicate can stick to plant surfaces, while ingredients of nanotube have the ability to stick to the surface hair of insect pests and ultimately enter the body and influence certain physiological functions.

**Advantages of nano-pesticides**

- Nano-pesticides reduce toxic impact of chemical pesticide, reduce environmental imbalance, stabilities of active ingredient and provide target specific control of crop pest
- They have controlled release pattern of active ingredient make them more efficient for long time period and reduces residual pesticide accumulation problem
- Nanoencapsulation of the pesticide minimize the doses and to get maximum effect with more target oriented action of the pesticides
- Nanopesticides reduces the doses of chemical as compare to the traditional pesticide and controls the release of toxic substances to the environment causing no harm to other beneficial organisms
- Nanopesticides gets absorbed in the surface of the plant and facilitates prolong release which lasts for longer time compared to conventional pesticides which washed away in the rain and reduces the frequent use of chemical pesticides
- Nano-pesticides provide a reliable and cheap alternative source for the management of insect pests

**6.19 RESURGENCE****■ Definition**

Resurgence can be defined as a situation where a population after having been suppressed rebounds to numbers greater than before suppression occurred.

Abnormal increase in pest population or damage following insecticide application, often far exceeding the economic injury level is called as resurgence.

**➤ Paradigm for resurgence**

When the insecticide is sprayed on the crop it reduces both pest and natural enemy population at the same time. As the effect of spraying decreases, the pest population grows, but because the natural enemies must wait for an adequate food

supply, their populations lag in re-growth. Unencumbered by natural enemies pest population growth accelerates and exceeds previous levels. If left untreated the natural enemies would finally return the pest to its original level, however, additional sprays are usually applied before this happens. Such continued activity results in a more or less permanent displacement of the natural enemy population.

➤ **Causes for resurgence**

The phenomenon called hormoligosis occurs when sub lethal quantities of a stressful agent increases organisms sensitivity and response to environmental factors. In several instances, this response has been increased reproduction.

Ex : Resurgence of *Helicoverpa* sp. after application of monocrotophos and aldicarb was caused by increased ovipositional preference.

Ex : Resurgence in the brown plant hopper on rice following methyl parathion and decamethrin treatments is caused by increased plant attractiveness, reduction in length of nymphal stadia and longer adult ovipositional period.

➤ **Main causes of insect resurgence are**

- Accelerated growth of insects
- High fecundity
- Suppression of natural enemies
- Competitive displacement of one species by another
- Increased nutritive value of the host
- Frequency, method and indiscriminate use of insecticides

➤ **Managing resurgence**

**Resurgence can be managed by**

- a. Avoiding hormoligosis
- b. Avoiding natural enemy destruction
- c. Physiological selectivity
- d. Ecological selectivity

**a. Avoiding hormoligosis**

Sub lethal doses can be minimized by applying insecticides on target and avoiding drift. In other words following the rules of good pesticide practice,

including proper chemical and formulation selection, can significantly lessen the problem.

**b. Avoiding natural enemy destruction**

Insecticides selectivity: Use of selective chemicals that have a stronger depressive influence on the pest population than on its natural enemies. This form of selectivity has been termed as physiological selectivity.

Another way is to use otherwise non selective chemicals in a selective manner. This is called ecological selectivity

**c. Physiological selectivity**

Some of the more important examples of physiological selectivity are found with non-conventional materials like microbial insecticides and some insect growth regulators.

**d. Ecological selectivity**

- a. Monitor population and follow recommended economic thresholds. This will conserve natural enemies, amount of insecticide applied and still provide economic returns
- b. Treat with lowest rates possible. Leaving a residual pest population usually results in natural enemy conservation and provide hosts for population recovery
- c. Avoid treating broad areas. Untreated areas can serve as refugia for natural enemies. This approach works best with relatively immobile pests like scales and highly mobile natural enemies like braconid parasitoids.
- d. Time treatments to avoid heaviest natural enemy destruction
- e. Use of most selective insecticides formulation. In some instances changing to another insecticides formulations can aid in achieving a degree of selectivity

➤ **Measures to minimize resurgence**

- The use of right type of insecticide, dosage, time and method of application can play a significant role in reducing the risk of insect resurgence
- The agronomic practices like date of sowing, judicious use of fertilizers and water are helpful in reducing resurgence
- The conservation of natural enemies and the use of eco-friendly approaches to pest management can help in avoiding resurgence.



# Host Plant Resistance

UNIT

7

## 7.1 MECHANO AND CHEMO RECEPTORS

### ■ Chemical ecology

Chemical ecology is the study of the chemicals involved in the interactions of living organisms. It focuses on the production of and response to signaling molecules (i.e. semiochemicals) and toxins.

Insects perceive signals by

- I. Mechanoreceptors
- II. Chemo receptors

### I. Mechanoreceptors

Insect mechanoreceptors are found on the surface of an insect's body. They may act as tactile receptors, detecting movement of objects in the environment, or about the orientation of the body. These receptors are innervated by one or more sensory neurons in response to stretching, bending, compression, vibration, or other mechanical disturbance. These mechanoreceptors may produce a phasic response or tonic response.

**Different types of mechanoreceptors present in insects are**

1. Trichoform sensilla
2. Campaniform sensilla
3. Stretch receptors
4. Pressure receptors
5. Chordotonal organs

1. **Trichoform sensilla** : These are probably the simplest mechanoreceptors. These are tactile hairs (setae) that are innervated by a sensory neuron. Dendrites of the neuron attach near the base of the hair and generate a nerve impulse whenever they detect movement. These are found behind the head, on the legs, or near joints where they respond to movements of the body.
2. **Campaniform sensilla** : These are flattened oval discs that usually serve as flex receptors in the exoskeleton. They respond whenever mechanical stress causes the

exoskeleton to bend. These are found throughout the body especially on the legs, near the base of the wings and along sutures.

3. **Stretch receptors** : These are multi - polar neurons that usually accompany muscle or connective tissue. They are commonly embedded in inter segmental membranes and in the muscular walls of the digestive system. Some insects may stop feeding when the gut expands enough to stimulate stretch receptors in the crop. In others, oviposition may begin when mature eggs stimulate stretch receptors in the reproductive system.
4. **Pressure receptors** : These provide sensory information about an aquatic insect's depth in the water. These receptors are usually associated with a cushion of air against the body or within the tracheal system. Increasing water pressure deflects hair-like processes within the receptor and stimulates tonic and phasic impulses.
5. **Chordotonal organs** : These include several types of mechanoreceptors in which one or more bipolar neurons bridge a gap between two internal surfaces of the exoskeleton. Each neuron is usually accompanied by two other cells which form a sheath (the scolopale cell) and a point of attachment (the cap cell). Together, these three cells create a unit (called a scolopidia) that may occur singly or in groups.

**There are 3 types of chordotonal organs**

- i) **Subgenual organs**: These are located on the legs of many insects, these receptors contain relatively few scolopidia yet they appear to be very sensitive to substrate vibrations. Insects may lack specialized sound receptors, yet they can still hear vibrations transmitted through the substrate.
- ii) **Tympanal organs**: These lie beneath a drum-like membrane (the tympanum) where they respond to sound vibrations. These are located on the thorax (Hemiptera), on the abdomen (grasshoppers, cicadas, and some moths), or on the front tibia (in crickets and katydids).
- iii) **Johnston's organs**: These are found within the pedicel of each antenna. In some insects, they function as a proprio-receptors, supplying information on position or orientation of the antennae.

## II. Chemoreceptors

Insects have the ability to sense various chemical substances in their environment. When these chemicals are present in gaseous form (at relatively low concentrations), they may be detected as odors (smells) by olfactory receptors

When they are in solid or liquid form (usually at higher concentrations) they are perceived as tastes by gustatory receptors.

In general, the sense of taste involves direct contact with a substrate (contact chemoreception) whereas olfaction usually implies detection of compounds in

gaseous or airborne form (remote chemoreception).

Chemical sense of insects corresponds to

1. Taste
2. Smell
3. Common chemical sense

#### 1. Taste

Gustatory receptors are commonly described as thick-walled hairs, pegs, or pits where the dendrites of several sensory neurons are exposed to the environment through a single opening in the cuticle. Each neuron appears to respond to a different range of compounds (*e.g.* sugar, salt, water, protein, acid, etc.). Taste receptors are most abundant on the mouthparts, but may also be found on the antennae, tarsi, and ovipositor.

#### 2. Smell

Olfactory receptors are usually thin-walled pegs, cones, or plates with numerous pores through which airborne molecules diffuse. Dendrites of sensory neurons branch profusely within these pores and may respond to very low concentrations of detectable compounds (sex pheromones). Some receptors respond to a wide range of substances while others are highly specific. Olfactory receptors are most abundant on the antennae, but may also be associated with the mouthparts or external genitalia.

#### 3. Common chemical sense

High concentrations of irritant compounds (essential oils) simulate avoidance reactions and cleaning behavior. Insects can detect these compounds even when all known chemoreceptors have been covered or destroyed. The irritants evidently trigger a generalized response from other types of sensory neurons.

## 7.2 HOST PLANT SELECTION

### ■ Host plant selection by phytophagous insects

#### Host selection process

It involves 5 phases. They are

1. Host - habitat finding
2. Host finding
3. Host recognition
4. Host acceptance
5. Host suitability

1. **Host - habitat finding** : Adult populations of insects reaches a general host habitat using mechanisms like anemotaxis, phototaxis, geotaxis and probably temperature and humidity preference. Normally most agricultural pests stay within the general area where crops are planted and hence this phase becomes less important in host selection.
2. **Host finding** : Long range sensorial mechanisms such as visual and olfactory bring the insect into close contact of the plant. However, chemosensory inputs from the characteristic emanations of volatiles from growing plants are important in specific host finding.
3. **Host recognition** : Host recognition is facilitated by specific volatiles, and oviposition is characteristically triggered by a combination of olfactory and gustatory inputs.
4. **Host acceptance** : Host acceptance is usually determined by 'test biting' or by ovipositional probing. In the host acceptance process, insect-feeding behaviour undergoes three phases: i.e. initiation, continuation and cessation of feeding at the point of satiation.
5. **Host suitability** : Host suitability is determined by the nutritional value of the plant in terms of sugars, amino acids, lipids, proteins and vitamins, and by the absence of deleterious factors such as toxic compounds.

### 7.3 SECONDARY PLANT METABOLITES

The plant defense chemicals perform allelochemical functions as

1. Allomones
2. Kairomones

1. **Allomones** : These provide adaptive advantage to the plants by acting as insect repellents, suppressants, deterrents and toxins.
2. **Kairomones** : These in plant function as insect attractants, feeding or oviposition stimulants.

Allelochemicals are vast array of secondary plant metabolites which have played an indispensable role in maintaining the plant species during the course of evolution. These metabolites are synthesized from primary metabolites in a dynamic state. Biosynthesis of these compounds are specific, genetically controlled and enzymatically catalyzed. Some of the toxic compounds may act as storage for carbon and nitrogen. Besides the basic necessity for plants, secondary metabolites play an important role in the defense against insect herbivores as they act as insect repellents, feeding inhibitors and toxins, thus protecting plants at different phases



of growth. Some of the plant volatile compounds attract insects for feeding, mating, and pollinating whereas, other repel potential invaders.

Secondary compounds can be grouped into different classes based on their biosynthesis pathways. There are 3 major pathways for the production of secondary metabolites in plants. They are

1. The acetate malonate pathway
2. The acetate mevalonate pathway
3. The shikimic acid pathway

These biosynthesis pathways are complex and interrelated. Specific secondary compounds are synthesized in their respective pathways.

Many secondary metabolites such as alkaloids, steroids, foliar phenolics esters (rutin, chlorogenic acid etc.) terpenoids, cyanogenic glycosides, glucosinolates, saponins, flavonoids, pyrethrins and non protein amino acids act as potent protective chemicals against pests.

## 7.4 HOST PLANT RESISTANCE

**Host plant resistance** (HPR) describes a range of adaptations evolved by plants which improve their survival and reproduction by reducing the impact of herbivores. Plants use several strategies to defend against damage caused by herbivores.

### Definition

Those characters that enable a plant to avoid, tolerate or recover from attacks of insects under conditions that would cause greater injury to other plants of the same species. (Snelling, 1941).

It is the relative amount of heritable qualities that influence the ultimate degree of damage done by the insect (Painter, 1951).

Those heritable characters possessed by the plant which influences the ultimate degree of damage done by the insects (Maxwell, 1972).

### ➤ Characterization of resistance

- Resistance is heritable and controlled by one or more major genes
- Resistance is relative and can be measured only with susceptible cultivar of some species
- Resistance is measurable and its magnitude can be determined quantitatively
- Resistance is variable and can be modified by abiotic and biotic components

➤ **Advantages and limitations of HPR****Advantages**

**Specificity** : Resistance variety is against a specific pest thus it does not have any detrimental effect to beneficial organisms

**Cumulative effect** : The effect of host plant does not end with one generations of the pests but lasts against successive generations.

**Persistence** : Most resistance varieties maintain high level of resistance for a long period of time

**Ecologically safe** : Increases in species diversity in the agroecosystem, in part because of reduced use of insecticides. Increases in species diversity increase ecosystem stability which promotes a more sustainable system far less polluted and detrimental to natural resources.

**Ease of adoption** : It can be easily incorporated with normal farm operations with little / no extra cost

**Compatibility** : It is compatible with other strategies of pest management

**Economical** : Money is saved by not applying insecticides that would have been applied to susceptible varieties. Seed of insect-resistant cultivars costs no more, or little more, than for susceptible cultivars.

**Effectiveness** : Resistant host make pests weak or will suppress the population so that efficiency of natural enemies on these population is increased.

**Unique situations** : Host plant resistance serves as means of control of pests in unique situation such as i). When insect is exposed only for brief period of its life cycle ii). Crop is of low economic value (Ex: castor) iii). Pest is continuously present and is a single limiting factor over a large area

**Limitations**

- It takes long time to develop a resistance variety
- Development of biotypes
- Genetic limitations
- High initial cost

## 7.5 MECHANISM OF RESISTANCE

### ➤ Mechanism of resistance

R.H.Painter classified mechanisms of resistance into 3 main categories

I. Non preference (Antixenosis)

II. Antibiosis

III. Tolerance

Antixenosis is employed by the plant to deter or reduce colonization by insects. Plants that exhibit antixenotic resistance should have a reduced initial number of colonies early in the season. Antibiosis operates after the insect have colonized and have started utilizing the plant. Tolerance of the plant does not affect the rate of population increase of the target pest but does raise the threshold level.

### I. Non preference

It refers to plant characteristics that lead insects away from a particular host; it includes activities of both plant and insect. It is also called as Antixenosis. Xenosis is Greek word meaning “guest” therefore, Antixenosis means against or expelling guests.

It refers to the response of insect to the characteristics of the host plant which make it unattractive to the insect for feeding, oviposition or shelter. It denotes the presence of morphological or chemical plant factor that adversely alter insect behaviour resulting in poor establishment of the insect.

Nonpreference is of 2 types

A. Morphological nonpreference

B. Allelochemic nonpreference

#### A. Morphological nonpreference

Morphological characters of plant interfere with insect behaviour activities such as mating, oviposition, feeding and feeding ingestion.

Various morphological characters are

1. **Trichomes** : Trichomes affect locomotion, attachment, shelter, feeding, digestion and oviposition of insect and the effect depends on density, length and shape of trichomes.

Ex : Hooked trichomes in French bean offer resistance to aphid, *Aphis craccivora*

2. **Pubescence** : Insects with piercing and sucking mouth parts are deterred from feeding on hairy plants or vascular bundles.

Ex : Cotton varieties with pubescence offer resistance to leaf hoppers and whiteflies by preventing egg laying

Corn ear worm, *Helicoverpa zea*, prefers to oviposit on pubescent surfaces

3. **Surface waxes :** Epicuticular waxes affect the feeding behavior of insects. They also effect colonization and oviposition.

Ex : Wax bloom on leaves of crucifers deter feeding by diamond back moth  
Bloomlessness and sparce bloom sorghum varieties confer resistance to aphid, *Schizaphis graminum*

In onion glossy foliage provide more resistance to thrips

4. **Thickness of cell wall and proliferation of plant tissues:** Cell walls thickening affect the feeding behaviour of insects.

Ex : Rice varieties containing thicker hypodermal layers offer resistance to stem borer.

Stem density of pith and node tissues in wheat resists damage by the wheat stem fly

5. **Silica content :** Silica content in leaves affect the madibules and greatly reduce the feeding. Not only the total silica content but also distribution of silica in leaves play an important role.

Ex : Silica in the rice leaves affect the feeding of stem borer

6. **Solidness and other stem characters :** These characters obstruct feeding and oviposition by insects.

Ex : Hard woody stems with closely packed vascular bundles in cucurbits resists feeding of squash vine borer, *Melittia cucurbitae*

Pomegranate varieties having rind thickness are resistant to fruit sucking moth

Rind hardness coupled with high fibre content confer resistance to shoot borer in sugarcane

Stem density of pith and node tissues in wheat resists damage by the wheat stem fly

7. **Anatomical adoptions of organs:** Slight variation in the morphological structure of plants may result in altered fitness to herbivores

Ex : Nectariless cotton varieties are resistance to pink bollworm

Sorghum varieties having leaves tightly wrapped around the stem are resistance to shoot bug

Husk tightness in corn resists damage from corn ear worm

8. **Colour and intensity of light :** The colour and shape of plants remotely

affect host selection behaviour of phytophagous insects and have been associated with some resistance.

Ex : Yellow colour is preferred by aphids

Green and blue green is preferred by cabbage butterfly

Dark green preferred by rice leaf folder

#### **B. Allelochemic nonpreference**

Several chemical present in the plant affect the olfactory and gustatory stimuli in insects. These chemicals may attract or repel the insects and also inhibit feeding by the insects.

Ex : In cucurbits, a compound called cucurbitacin acts as an attract and feeding incitant to spotted cucumber beetles

## **II. Antibiosis**

It refers to the adverse effect of the host plant on the biology (survival, development or reproduction) of the insects and their progeny infesting it due to the bio-chemical and biophysical factors present in it. This influences both behaviour response and physiological responses.

### ➤ **Symptoms of insects affected by antibiosis include**

- Death of young immatures
- Reduced growth rate
- Increased mortality in pupal stage
- Small adults with reduced fecundity
- Shortened adult life span
- Morphological malformations
- Restlessness and other abnormal behaviour

These symptoms may appear due to various physiological processes such as presence of toxic substances, absence or insufficient amount of essential nutrients, nutrient imbalance or improper utilization of nutrients.

This mechanism impairs an insect metabolic processes and involves consumption of plant metabolites. Both insect and plant factors are involved in the antibiosis mechanism.

The physiological explanations for antibiosis are

- Presence of toxic metabolites such as alkaloids, glucosides
- Absence / insufficiency of essential nutrients

- Unbalanced proportion of nutrients
  - Presence of antibodies
  - Presence of enzymes
1. **Presence of toxins :** Presence of toxic metabolites such as alkaloids and glucosides play an important role in resistance to insects.  
Ex : Corn is resistant to southern corn borer due to the presence of 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA). Its higher concentrations are typically found in young plants and the concentration decreases as the plant ages.
  2. **Absence / insufficiency of essential nutrients :** The nutritional composition of plant tissue strongly influences the growth development, reproduction and survival of insect. Quantity and quality of primary metabolites also play important role in conferring antibiosis.  
Ex : Rice cultivars deficient in asparagines causes reduced fecundity in brown plant hopper
  3. **Unbalanced proportion of nutrients :** Imbalances of sugar and amino acids results in nutritional deficiencies for insects feeding on the plant.  
Ex : Pea cultivars with low amino acids levels and an increased sugar content show resistance to pea aphid, *Acyrtosiphon pisum*
  4. **Presence of antibodies :** Presence of antibodies offer resistance to insect pests.  
Ex : Cotton varieties rich in gossypol offer resistance to bollworms.  
Steroidal glycosides in potato and saponins in alfalfa offer resistance to insects.

### III. Tolerance

Tolerance refers to the ability of the host plant to with stand an insect population sufficient to damage severely the susceptible plants.

Tolerance is a plant response to an insect pest. Whereas, antibiosis and antixenosis resistance cause an insect response when the insect attempts to use the resistant plant for food, oviposition, or shelter.

This form of resistance include general vigour, compensatory growth in individual plants and or the plant population, wound healing, mechanical support in tissues and organs and changes in photosynthate partitioning.

➤ **Advantges and limitaions of tolerance****Advantges**

- Tolerant varieties have higher ETL
- They prevent development of biotypes
- They increase yield stability

**Limitations**

- Insect popuatlions are allowed to sustian epidemics in an area, causing problems in other crops
- It is more strongly affected by environmental extremes than other forms of resistance

## 7.6 PHYSICAL AND BIOCHEMICAL BASIS OF HOST PLANT RESISTANCE

### Physical factors associated with host plant resistance to insects

| S.No. | Plant factors                                                           | Effect on insects                                                      |
|-------|-------------------------------------------------------------------------|------------------------------------------------------------------------|
| 1     | Trichomes                                                               | Effect on feeding, oviposition, digestion and locomotion               |
| 2     | Thickening of cell walls, increased toughness of tissues                | Interference with feeding and oviposition mechanisms                   |
| 3     | Proliferation of wounded tissues                                        | Insect killed after initial injury                                     |
| 4     | Solidness and other characteristics of stems                            | Obstruction of feeding and oviposition mechanisms, dehydration of eggs |
| 5     | Accumulation of surface waxes                                           | Effect on colonization and oviposition                                 |
| 6     | Incorporation of silica                                                 | Abrasion of mandibles and feeding inhibition                           |
| 7     | Anatomical adaptations of non specific organs and protective structures | Various effects                                                        |

**Biochemical basis of host plant resistance to insects**

| S.No      | Allelochemicals                   | Effect on behaviour and physiology of insect                                                  |
|-----------|-----------------------------------|-----------------------------------------------------------------------------------------------|
| <b>I</b>  | <b>Allomones</b>                  | Adaptive advantage to producing organism                                                      |
| 1         | Repellents                        | Orient insect away from host plant                                                            |
| 2         | Locomotor excitants               | They speed up / start movement                                                                |
| 3         | Suppressants                      | They inhibit biting and piercing                                                              |
| 4         | Deterrents                        | They prevent feeding and oviposition                                                          |
| 5         | Antibiotics                       | They disrupt normal growth and development of larvae reduce longevity and fecundity of adults |
| 6         | Antixenotics                      | Disrupt normal host selection behaviour                                                       |
| <b>II</b> | <b>Kairomones</b>                 | Adoptive advantage to receiver                                                                |
| 1         | Attractants                       | They orient insect towards the host                                                           |
| 2         | Arrestants                        | Slow down / stop movement                                                                     |
| 3         | Feeding and oviposition excitants | Elicit biting, piercing, oviposition and promote continuation of feeding                      |

**7.7 TYPES OF RESISTANCE****➤ Types of resistance**

Host plant resistance to insect is divided into different categories based on several parameters

**I. Ecological resistance**

1. Host evasion
2. Induced resistance
3. Escape

**II. Genetic resistance**

1. Oligogenic resistance
2. Polygenic resistance
3. Cytoplasmic resistance

**III. Evolutionary concept**

1. Sympatric resistance
2. Allopatric resistance



#### IV. Biotype reaction

- |                        |                          |
|------------------------|--------------------------|
| 1. Vertical resistance | 2. Horizontal resistance |
|------------------------|--------------------------|

#### V. Based on number of genes

- |                          |                          |
|--------------------------|--------------------------|
| 1. Major gene resistance | 2. Minor gene resistance |
| 3. Monogenic resistance  | 4. Oligogenic resistance |
| 5. Polygenic resistance  |                          |

#### VI. Intensity of resistance

- |                        |                      |
|------------------------|----------------------|
| 1. Immunity            | 2. Highly resistance |
| 3. Low resistance      | 4. Susceptibility    |
| 5. High susceptibility |                      |

#### I. Ecological resistance

It is also called as apparent resistance or pseudo-resistance. It is not considered as true resistance because expression depends on environmental conditions than on genetics and no heritable trait is involved.

Ecological resistance is of 3 types

##### 1. Host evasion

In this the plant passes through a susceptible stage quickly or at a time such that its exposure to potentially injurious insects is reduced.

Ex: Planting of fast fruiting and short season cotton varieties against *Helicoverpa armigera* and pink bollworm

##### 2. Induced resistance

It is form of temporary resistance derived from plant condition or the environment. Factors like fertilization or change in soil moisture levels may make plants more tolerant of insects than under other circumstances.

Ex: Balanced fertilization of nitrogen and potassium induce resistance to aphids  
Phytoalexins:

These play an important role in inducing resistance to insects. These are phenolic compounds produced by plants when they become diseased or are attacked by insects. These compounds enable plants, once fed upon, to resist further damage by the pests. The mechanism involved results from an accumulation of allomones triggered by the injury or environmental factors.

##### 3. Escape

Escape refers to the absence of infestation or injury to the host plant because of transitory circumstances such as incomplete infestation. This pertains to one or few individuals of a population.

**II. Genetic resistance**

P. R. Day recognized 3 major resistance categories, oligogenic, polygenic and cytoplasmic based on the mode of inheritance

1. **Oligogenic** : It is also called as major gene resistance and is conferred by one or only a few genes. This type usually produce vertical resistance against insects and may be inherited through dominant or recessive genes.

Ex : Wheat varieties resistant to Hessian fly

2. **Polygenic resistance** : It is conferred by many genes, each contributing to the resistance effect. It is also called as minor gene resistance. Horizontal resistance is usually polygenic.

Ex : Corn varieties resistant to European cornborer

3. **Cytoplasmic resistance** : It is conferred by mutable substances in cell cytoplasm. Cytoplasmic inheritance is maternal because most cytoplasm of the zygote comes from the ovum. It has not been factor of resistance to insects.

**III. Evolutionary concept**

1. **Sympatric resistance** : Evolved as a result of gene for gene nature of co evolution of plant and insect. It is governed by many factors.
2. **Allopatric resistance** : Evolved not as a result of coevolution of plant and insect. It is governed by many genes.

**IV. Biotype reaction**

J.E. van der Plank recognized 2 types of resistance, vertical and horizontal

1. **Vertical resistance** : It refers to the cultivars with resistance limited to one or few pest genotypes. It is also called as specific resistance. It is qualitative as the frequency distribution of resistant and susceptible plant is discontinuous.
2. **Horizontal resistance** : It describes cultivars that express resistance against a broad range of pest genotypes. It is also called as non specific resistance. It is quantitative as the degree of resistance depends on the number of minor genes each contributing to a small affect.

**V. Based on number of genes**

1. **Major gene resistance** : It is controlled by one or few major genes and it is also called as vertical resistance.
2. **Minor gene resistance** : It is controlled by a number of minor genes. It is also called as horizontal resistance.
3. **Monogenic resistance** : It is controlled by single gene. It is easily incorporated

into breeding programme and it is easily broken.

4. **Oligogenic resistance**: It is controlled by few genes.

5. **Polygenic resistance**: It is controlled by many genes.

## 7.8 BIOTYPE DEVELOPMENT AND ITS REMEDIAL MEASURES

### ■ Biotypes

New population capable of damaging and surviving on plants previously resistant to the populations of same species. Certain physiological and behaviour changes in the new populations of insect make it easy to feed and develop on resistant varieties.

The term biotype is an intraspecific category referring to insect population of similar genetic composition for a biological attribute.

Different populations of an insect species that vary in their virulence to a cultivar are referred to as biotypes. Hessian fly, *Mayetiola destructor* has developed 16 biotypes. Most insect biotypes have developed among aphid pests.

Ex : Biotypes of brown plant hopper (BPH) of rice

Biotype 1 ..... destroy varieties with resistant gene (TN1)

Biotype 2 ..... thrives on varieties with BPH 1 gene (Mudgo)

Biotype 3 ..... thrives on varieties with BPH 2 gene (ASD7)

Biotype 4 ..... thrives on varieties with BPH 3 gene (Ratu Heenati)

Biotype 5 ..... thrives on varieties with BPH 4 gene

### ➤ Remedial measures

- Sequential release : When a variety with a major gene becomes susceptible due to selection for a new biotype, another variety with a new major gene for resistance is released
- Gene pyramiding: Two or more major genes for vertical resistance are incorporated into a variety to impart resistance to more biotypes and also increase the stability of resistance
- Horizontal resistance : The level of horizontal resistance and its stability maybe enhanced by increasing the number of minor genes in variety
- Minor genes may be combined with major genes

- Gene rotation : The major genes may be rotated by seasonally alternating varietal groups having different major genes so that the selective pressure of the resistant variety on insect population may be reduced
- Geographical deployment : The planting of varieties with different R (resistant) genes in adjacent cropping areas
- Breeding tolerant varieties with combination of major genes will decrease the insect population and provide a high level of resistance

## 7.9 TRITROPHIC INTERACTIONS

### ■ Tritrophic interactions

Interaction among host plants, insects and their natural enemies is called tritrophic interaction. It leads to effective defense and attack at each level. When the plant alone produce defense through physical means or through production of chemicals or both it is called intrinsic resistance. When the natural enemies of insect pests benefit the host plants by reducing the pest abundance is called extrinsic resistance. The physical, morphological, physiological and chemical characteristics of plants interact with the parasitoids and predators of the insects by influencing their host seeking ability and affecting the efficacy with which they locate and utilize hosts.

The resistant varieties play an important role in

- Increasing the searching behaviour of natural enemy
- Decreases the vigour of the herbivorous insect so that it is easily attacked
- Delays the development of the insect so that it is more exposed to natural enemy

Plants provide nutrition to the natural enemies in the form of pollen and nectar. Insects such as aphids and whiteflies which secrete honey dew attract ants which also keep herbivorous insects away. The growth and development of insects is affected by anti metabolites and enzyme inhibitors present in the plants. So smaller hosts with longer life cycle are available which can be exploited by natural enemies more successfully.

### ➤ Chemical factors

Toxins present in plants are taken up by herbivores and these provide defense against their natural enemies.

Ex : Monarch butterfly sequesters cardiac glycosides from milk weed plants so that it becomes distasteful to predatory birds.

Aphid, *Brevicoryne brassicae* uses sinigrin as a cue to find host plant but its parasitoid, *Diaeretiella rapae* uses allyl-isothiocyanate to find the host habitat and then the host.

Volatile compounds released by the molasses grass when intercropped with maize stimulate the parasitization of *Chilo partellus* by *Apanteles sesamiae* on maize.

➤ **Physical factors**

- Leaf toughness slow the larval development of Pierid butterfly and thus exposing them to natural enemies for longer period
- High rate of parasitization is recorded on moderately resistant varieties of pigeon pea which have fine epidermal hairs
- The searching behaviour of *Trioxys indicus* (Parasitoid of aphids) is influenced by pubescence of host plants

## 7.10 INDUCED RESISTANCE

### ■ Induced resistance

It is the qualitative or quantitative enhancement of a plant's defense mechanism against pests in response to external physical or chemical stimuli.

This is a non-heritable resistance where host plants are induced to impart resistance to tide over pest infestation.

Plant allelo chemical production is induced by an injury to the plant or by the mechanical disruption of plant tissues. These mechanical disruptions evoke photochemical responses such as cellular chemical changes, changes in cells adjacent to the damaged tissues a generalized changes in plant part or entire plant.

Induced responses have indicated changes in the levels of tannins and phenols, which are products of shikimic acid pathway.

The relative activity of the enzyme phenylalanine ammonia lyase (PAL) determines the production of phenolics and lignin. PAL activity is considered an important indicator of induced resistance.

Wounding plant tissues may induce changes in protein, lipid and phenol metabolism. Photochemical produced by damaged plants may be detrimental to insects

Ex: Feeding of *Spodoptera litura* is affected by the production of proteinase inhibitor produced by the mechanically wounded tomato plants.

Wounding induced the oxidation of plant phenols to produce toxic quinines and synthesis of mono and diphenols

Ex : Increase of phenols content following the damage by lygus bugs in Chinese cabbage

Increase in total phenol content in sugar maple tree foliage in adjacent and non connected trees following the insect attack

Phloem sap sucking insects which are passive feeders depend upon the plant turgor pressure for feeding. With the decrease in turgor pressure, insects stop getting feed from the plant. Immature citrus fruits are resistance to fruit fly due to the presence of peel oils which are composed of monoterpenes and terpenoids.

Endophytes (microbes such as fungi and bacteria) which grow entirely within the plant body either inter or intra cellularly provides resistance to plants.

There are 2 mechanisms by which resistance is manifested by endophytes in hosts

- They release antibiotic metabolites in the host in response to host attack
- They release hydrolytic enzymes to catalyze the reactions which releases defensive allelochemicals

Ex : Infection of turf grass with fungal endophyte, *Acremonium* sp. enhances resistance to aphids and green bug.

Resistance in ryegrass to webworm and bilbug has been associated with fungal endophyte

## 7.11 BREEDING FOR INSECT RESISTANCE PLANT VARIETIES

In traditional methods of plant breeding, the plant breeder identifies traits in a resistance cultivar and transfers these traits to another cultivar by crossing them. After an initial cross, the offspring or progeny of the cross are evaluated for the resistant trait. This process is repeated several times with subsequent generations of progeny, among other methods. In addition to levels of resistance in the resulting progeny, plant breeders also attempt to identify the resistance genes and measure their degree of expression in new cultivar. There are at least 8 traditional methods of breeding for insect resistance.

### ➤ Methods of developing resistant varieties

#### a. Screening of available germplasm

Available germplasm collections are sown at a time in a single row in a (hot spot areas) location where there is a moderate to heavy incidence and evaluated by comparing with susceptible and resistant check varieties.

**b. Selective screening under natural infestation**

Select promising lines from general screening and screen under natural condition in a single row or 2-3 rows in a replicated trial.

**c. Selective screening under artificial condition**

To test the true resistance, the selected varieties are screened under artificial conditions in which insects are mass multiplied and released over the plant. Results are compared with a resistant and susceptible check. Breeders start screening of lines or cultivars from F<sub>2</sub> to F<sub>6</sub> stages for yields and resistance. If found suitable they will be forwarded to multi location trials (MLT) and for Adaptive Research Trials (ART). If a line or cultivar is succeeding in all stages it will be released as a variety

## 7.12 BIOTECHNOLOGICAL APPROACHES

### ■ Biotechnology

It is defined as the integrated use of molecular genetics, biochemistry, microbiology and process technology to supply goods and services employing microorganism, part of microorganisms, or cells and a tissues of higher organism.

The 3 componenst of modern plant biotechnology are

- Recombinant DNA technology
- Monoclonal antibody production
- Cell and tissue culture

#### ➤ Development of Transgenic Plants

**The basic requirements of transformation are**

- A target genome
- A vector to carry the gene
- Modification of the foreign DNA to increase the level of gene expression
- Method to deliver the plasmid DNA into the cell
- Methodology to identify the transformed cell
- Tissue culture to recover the viable plants from the transformed cells

#### ➤ Transgenic plants

Genetically modified plants or transgenic plants are plants whose DNA is modified using genetic engineering techniques. In most cases the aim is to introduce a new trait to the plant which does not occur naturally in this species. Examples include resistance to certain pests, diseases or environmental conditions, or the production

of a certain nutrient or pharmaceutical agent.

Transgenic plants have been produced by addition of one or more following genes

1. Endotoxin gene from *Bacillus thuringiensis* (Bt)
2. Protease inhibitors
3. Alpha amylase inhibitors
4. Lectins
5. Enzymes
6. Pyramiding genes

1. **Endotoxin gene from Bt** : The gene responsible for producing endotoxin is isolated from Bt and cloned into plants to develop resistance to insects
2. **Protease inhibitors** : Insects have protease in their gut which are enzymes helping in digestion of protein. Protease inhibitors are substances inhibit the proteases and affect digestion in insects. The protease inhibitors genes are isolated from one plant and cloned into another to produce transgenic plants. There are four classes, serine, thiol, metallo and aspartyl-protease inhibitors. Out of these the first group serine protease inhibitor is the most important.

➤ **Advantages**

- Their activity against wide range of insects
- Their use as a second mechanism to help prevent development of insects that are resistant to endotoxin
- Their inactivation with cooking
- The common nature of such inhibitors in food of humans and animals

Ex : Cowpea trypsin inhibitor (CpTi) gene derived from cowpea and clones into tobacco against *Helicoverpa virescens*.

3. **Alpha amylase inhibitors**

Alpha amylase is a digestive enzyme present in insects for digestion of carbohydrates. Alpha amylase inhibitor effects digestion of carbohydrates in insects. Transgenic tobacco and tomato expressing alpha amylase inhibitor have been produced which are resistant to Lepidopteran pests.

4. **Lectin genes**

Lectins are a group of plant proteins that bind to carbohydrates, including chitin. The deleterious effect of chitin binding lectins on insect development is mediated by biding to chitin in the peritrophic membrane that lines the midgut of insect, thus interfering with the uptake of nutrients.

Ex : Gene encoding the pea lectin (P-Lec) has been expressed in transgenic tobacco against *Helicoverpa virescens*.



## 5. Enzymes

Chitinase enzyme gene, cholesterol oxidase and lipoxygenase genes have been cloned into plants. These transgenic plants show insecticidal properties.

Ex: Expression of bean chitinase (BCH) in transgenic tobacco against aphid.

## 6. Pyramiding genes

Engineering transgenic crops with more than one gene to get multi mechanistic resistance is called pyramiding of genes.

Ex: CpTi gene and pea lectin gene were cloned to produce transgenic tobacco. Lectins and bean chitinase genes were cloned to produce transgenic potato.

### ➤ Steps in the development of transgenic plants are

- I. Transforming Plants
- II. Selection and Regeneration
- III. Regeneration of whole plants

### I. Transforming Plants

Transformation is the heritable change in a cell or organism brought about by the uptake and establishment of introduced DNA. There are two main methods of transforming plant cells and tissues:

Most genetically modified plants are generated by

1. Biolistic method (particle gun)
2. *Agrobacterium tumefaciens* mediated transformation

#### 1. Biolistic method (particle gun)

It is also called as Gene Gun" method or microprojectile bombardment method. In the biolistic method, DNA is bound to tiny particles of gold or tungsten which are subsequently "shot" into plant tissue or single plant cells under high pressure. The accelerated particles penetrate both the cell wall and membranes. The DNA separates from the metal and is integrated into the plant genome inside the nucleus. This method has been applied successfully for many cultivated crops, especially monocots like wheat or maize, for which transformation using *Agrobacterium tumefaciens* has been less successful. The major disadvantage of this procedure is that serious damage can be done to the cellular tissue.

#### 2. *Agrobacterium tumefaciens* mediated transformation

*Agrobacteria* are natural plant parasites, and their natural ability to transfer genes is used for the development of genetically engineered plants. To create a suitable environment for themselves, these *Agrobacteria* insert their genes into

plant hosts, resulting in a proliferation of plant cells near the soil level (crown gall). The genetic information for tumour growth is encoded on a mobile, circular DNA fragment (plasmid). When *Agrobacterium* infects a plant, it transfers this T-DNA to a random site in the plant genome. When used in genetic engineering the bacterial T-DNA is removed from the bacterial plasmid and replaced with the desired foreign gene. The bacterium is a vector, enabling transportation of foreign genes into plants. This method works especially well for dicotyledonous plants like potatoes, tomatoes, and tobacco. *Agrobacteria* infection is less successful in crops like wheat and maize.

## II. Selection and Regeneration

Selection of successfully transformed tissues: Following the gene insertion process, plant tissues are transferred to a selective medium containing an antibiotic or herbicide, depending on which selectable marker was used. Only plants expressing the selectable marker gene will survive and it is assumed that these plants will also possess the transgene of interest. Thus, subsequent steps in the process will only use these surviving plants.

## III. Regeneration of whole plants

To obtain whole plants from transgenic tissues such as immature embryos, they are grown under controlled environmental conditions in a series of media containing nutrients and hormones, a process known as tissue culture. Once whole plants are generated and produce seed, evaluation of the progeny begins.

### ➤ Advantages and limitations of biotechnology

#### Advantages

- Transgenic plants are compatible with other tactics of management of insect pests
- Since all the plant parts are covered with toxins dependence of weather for efficacy of sprays would be eliminated
- There will be no need of continuous monitoring of pests
- Transgenic plants provide protection to those plant parts which are difficult to be treated with pesticides
- The cost of application of pesticides will be nil
- No problem of contamination of in the form of drift
- Since there are specific to target pest, hence safe to non target species and human beings
- Transgenic plants eliminate the problems of shelf life and field stability
- Reduce the use of chemical pesticides and minimizing the problem of environmental pollution

**Limitations**

- Development of resistance due to the continuous exposure of the insect to the toxin
- Problem of development of super weeds due to introgress of genes into the weeds
- Problem of secondary pest out break

### 7.13 DEVELOPMENT OF TRANSGENIC INSECT RESISTANT PLANTS

■ Biotechnology has opened up new vistas for pest control. They are

- Access to novel molecules
- Ability to change the level of gene expression
- Ability to change the expression pattern of genes
- Develop transgenics with different insecticidal genes

➤ **Bt insect resistant plants development**

Bt” is short for *Bacillus thuringiensis*, a soil bacterium whose spores contain a crystalline (*Cry*) protein. In the insect gut, the protein breaks down to release a toxin, known as a delta-endotoxin. This toxin binds to and creates pores in the intestinal lining, resulting in ion imbalance, paralysis of the digestive system, and after a few days, insect death. Different versions of the *Cry* genes, also known as “Bt genes”, have been identified. They are effective against different orders of insects, or affect the insect gut in slightly different ways.

More than 100 different variations of Bt toxin have been identified in diverse strains of *Bacillus thuringiensis*. The different variations have different target insect specificity.

| <b>Cry gene designation</b>                         | <b>Toxic to these insect orders</b> |
|-----------------------------------------------------|-------------------------------------|
| <i>CryIA(a)</i> , <i>CryIA(b)</i> , <i>CryIA(c)</i> | Lepidoptera                         |
| <i>CryIB</i> , <i>CryIC</i> , <i>CryID</i>          | Lepidoptera                         |
| <i>CryII</i>                                        | Lepidoptera, Diptera                |
| <i>CryIII</i>                                       | Coleoptera                          |
| <i>CryIV</i>                                        | Diptera                             |
| <i>CryV</i>                                         | Lepidoptera, Coleoptera             |

Recombinant technology to develop resistant plants has mostly involved inserting the gene responsible for producing delta endotoxin from insect pathogenic bacteria *Bacillus thuringiensis* (Bt) into plant genomes. With this approach, the transformed or transgenic plant has the power to produce the toxic protein in its tissues consequently killing feeding insects and protecting plant

In most instances the transgenic plants are developed with the use of a vector bacterium, *Agrobacterium tumefaciens*. This is a natural soil borne bacterium that causes crown gall disease in plants. *A. tumefaciens* is an efficient vector of DNA because it has the ability to transmit a fragment of its large plasmid into the nuclear genome of an infected cell. The fragment called T-DNA, transfer contained genes, know as oncogenes, that induce tumors in the plant tissues.

By understanding the site of the T-DNA, a fragment of DNA controlling delta endotoxin production from a Bt cell is inserted into the *A. tumefaciens* plasmid. The transgenic *Agrobacterium* is then used to transfer the delta endotoxin protein into the plant cell chromosomes. Subsequently, the plant cell is cultured and grown into a whole plant whose cells contain the toxin protein. These transgenic resistant plants then produce seed expressing the insect resistant trait, which can be commercialized. This procedure has been used to transfer Bt delta endotoxin gene to many plants, including cotton, tobacco, tomato and potato

#### List of transgenic plants carrying Bt genes for insect resistance

| S.No. | Crop      | Genes                                    | Target insect                                                                               |
|-------|-----------|------------------------------------------|---------------------------------------------------------------------------------------------|
| 1     | Brinjal   | <i>Cry IIIb</i>                          | <i>Leptinotarsa decemlineata</i>                                                            |
| 2     | Cotton    | <i>Cry 1A (b)</i> ,<br><i>Cry 1A (c)</i> | <i>Helcioverpa zea</i> , Pink bollworm.<br><i>Spodptera exugua</i> , <i>Trichoplusia ni</i> |
| 3     | Maize     | <i>Cry1A (b)</i>                         | <i>Ostrinia nubilalis</i>                                                                   |
| 4     | Poplar    | <i>Cry 1A</i>                            | <i>Lymmentria dispar</i>                                                                    |
| 5     | Potato    | <i>Cry 3A</i><br><i>Cry 1A (b)</i>       | <i>L. decemlineata</i><br><i>Phthorimaea operculella</i>                                    |
| 6     | Rice      | <i>Cry 1A (b)</i> ,<br><i>Cry 1A (c)</i> | Yellow stem borer, leaf folder,<br><i>Chilo suppressalis</i>                                |
| 7     | Sugarcane | <i>Cry 1A (b)</i>                        | <i>Diatraea saccharalis</i>                                                                 |
| 8     | Tobacco   | <i>Cry 1A (b)</i>                        | <i>Helicoverpa virescens</i>                                                                |
| 9     | Tomato    | <i>Cry 1A (c)</i>                        | <i>Manduca sexta</i>                                                                        |

## 7.14 ADVANTAGES AND LIMITATIONS OF TRANSGENIC PLANTS

### ➤ Advantages of transgenic plants

- More convenient and flexible to use
- Higher productivity and economic returns and safer environment through decreased use of conventional pesticides
- Advantage of conservation of soil moisture, structure, nutrients and control of soil erosion through no or low tillage practices
- Improved quality of ground and surface water with less pesticide residues
- The level of toxin expression can be very high thus delivering sufficient dosage to the target pest
- The toxin expression is contained within the plant system and hence only those insects that feed on the crop perish
- Transgenic plants would provide protection to those plant parts which are difficult to be treated with pesticides
- Since insecticidal activity of transgenic crops would be restricted to those insects which actually attack the plant, these would be safe to non-target organisms and human beings
- Since all plant parts including growing points would remain covered with toxins, dependents on weather for efficacy would be eliminated

### ➤ Limitations

- Greatest ecological hazard of transgenic crops is the creation of new weeds
- The erosion of genetic diversity due to the exchange of genetic material between transgenic crops and their native wild relatives
- Genetic exchange between land races and transgenic material
- Rapid development of resistance in pest population due to continuous selection pressure
- Secondary pest incidence : If lepidopteran herbivores were removed from plant species, other insects might increase in number and create more problems
- The disruption of pollinators and plant communities would occur if the toxin is expressed in plant nectar and pollen
- A new disease called Colony Collapse Disorder (CCD) is affecting bee hives and it is supposed to be the use of Bt resistant transgenic crops

## 7.15 INSECT RESISTANCE TO TRANSGENIC PLANTS AND ITS MANAGEMENT

*Bacillus thuringiensis* (*Bt*) products had been used for more than 40 years without any evidence of resistance in field situations until a report from the Philippines indicated control failures of the diamond back moth (DBM), *Plutella xylostella*. Subsequent studies in Hawaii and Florida documented the genetic basis of resistance of *Bt* against DBM in other parts the world. Laboratory populations of at least 10 species of moths, two species of beetles and four species of flies have been exposed to selection against *Bt* toxins and ten-fold increases in tolerance have occurred in nine of the 16 species. These findings warn of the possibility of insects developing resistance to transgenic insecticidal plants containing *Bt* toxins. Under laboratory conditions, significant resistance to *Bt* was developed by a *Plodia interpunctella* strain and *Heliothis virescens*. More over the development of field resistance of *Plutella xylostella* to *Bt* has indicated that this may be a real problem

### ➤ Resistance management

- Mortality source diversification or gene pyramiding (two or more highly fatal toxins with different modes of action could be combined in the same plant)
- If resistance to *Bt* protein increases slowly than new *Bt* insecticidal genes can be introduced
- Use of refugia (Combination of seed products containing *Bt* insecticidal protein with a small proportion that lacks the insecticidal protein) to reduce of selection pressure
- High dose: Market crops with very high levels of *Bt* protein expression to kill marginally resistant insects
- Increasing the activity of *Bt* transgenic plants by the addition of genes expressing serine protease inhibitors, tannic acid and CpTi genes
- Destruction of carry over population that have been exposed to *Bt* crops in previous generations
- Following appropriate crop rotation, observing a crop free season and other resistance strategies
- Alternate use of chemical pesticide and crops containing *Bt* insecticidal protein
- Use of economic thresholds for undertaking control operations
- Monitor plant growth and onset of insect infestation
- Monitor levels of resistance to insecticides to decide on appropriate control methods

- Avoid using broad-spectrum insecticides early in the season
- Monitor populations of the secondary pests and use appropriate control measures
- Prediction and monitoring of resistance
- Policy implementation

➤ **Strategies for managing resistance to Bt**

|                    |                                                                       |
|--------------------|-----------------------------------------------------------------------|
| Protein pyramiding | Multiple <i>Cry</i> genes<br><i>Cry</i> plus other insecticidal genes |
| Protein synthesis  | Constitutive<br>Tissue specific<br>Chloroplast specific<br>Inducible  |
| Field tactics      | Refuges (spatial, temporal)<br><i>Cry</i> gene crop rotation          |





# Innovative Approaches in Pest Control

## 8.1 TYPES OF PHEROMONES AND USES

### ➤ Semiochemicals

The term is derived from a Greek word 'someone' meaning a mark or a signal. Chemicals which modify behaviour in perceiving organisms at sub micro/nano gram levels are known as semio-chemicals. These are employed both for intra-and inter-specific communication systems. The compounds, which convey information between members of the same species, are known as pheromones and if the message is inter-specific, the compounds are known as allelo-chemicals.

### ➤ Pheromones

A pheromone is a secreted or excreted chemical factor that triggers a social response in members of the same species. Pheromones are chemicals capable of acting outside the body of the secreting individual to impact the behavior of the receiving individual.

The term "pheromone" was introduced by Peter Karlson and Martin Lüscher in 1959, based on the Greek word *pherein* (to transport) and *hormone* (to stimulate). They are also sometimes classified as ecto-hormones. These chemical messengers are transported outside of the body and result in a direct developmental effect on hormone levels or behavioural change.

Pheromones are of 2 types

1. **Releaser effect pheromones**: These produce an immediate and reversible behavioural change in the receiving insects. They operate through the olfactory sensillae.
2. **Primer effect pheromones**: These trigger a chain of physiological changes in the body of the insect and operate through gustatory sensillae. These regulate caste determination and reproduction in social insects.

Types of releaser effect pheromones

- |                     |                           |
|---------------------|---------------------------|
| 1. Sex pheromones   | 2. Aggregation pheromones |
| 3. Alarm pheromones | 4. Trail pheromones       |



1. **Sex pheromones :** Many insect species release sex pheromones to attract a mate, and these are well studied in many lepidopterans (moths and butterflies). Bombykol is the first sex pheromone isolated and identified from silkworm, *Bombyx mori* in 1959 by A. Butenandt and co-workers. Important sex pheromones which have a potential in pest management are disparlure (gypsy moth), gossyplure (pink bollworm), grandlure (cotton grey weevil), looplure (*Trichoplusia ni*) Helilure (*Helicoverpa armigera*) and Litlure (*Spodoptera litura*). Sex pheromones of *Earias vittella*, *E. insulana*, *Pectinophora gossypiella* etc., are also used in pest management.
2. **Aggregation pheromones :** These pheromones induce aggregation or congregation of insects for protection, reproduction and feeding. They also function in defense against predators, mate selection, and overcoming host resistance by mass attack. Ex : Frontalin (*Dendroctonus*), ipsenol (*Ips*), periplanone (*Periplaneta*) and dimethyldecanol (*Tribolium*)
3. **Alarm pheromones :** These are primarily an antipredator device, a warning to conspecific about the presence or attack of an enemy. This warning elicits different behaviour such as dispersion or escape in different insects. Ex : Terpenes (Aphids), aldehydes (Hemipterans), formic acid (Ants) and monoterpene hydrocarbons (Termite soldiers).
4. **Trail pheromones :** These are used to find mates, or to utilize food resources more efficiently. Ex : Caproic acid (*Zootermopsis* sp.), hexanoic acid and heptanoic acids (Ants)

➤ **Allelochemicals**

A substance that is significant to organisms of a species different from its source, for reasons other than food.

Different types of allelochemicals are

- a) **Allomone :** A compound released by one organism which evokes a reaction in an individual of a different species that is favourable to the emitter but not to the receiver. Ex : Citral which is a mandibular secretion of many ants and bees acts as a defensive allomone for ants and an attractant for bees.
- b) **Kairomone :** A compound released by one organism which evokes a response beneficial to receiver but not to the emitter. Ex : Male sex pheromone of bug, *Nezara viridula* acts as an attractant to its parasite, the tachnid fly, *Trichopoda pennipes*

- c) **Synomone** : A substance released by organism which benefits both the sender and the receiver.
- d) **Antimone** : A substance produced or aquired by an organsim that when it contacts an individual of another species in the natural context, evokes in the receiver a behaviour or physiological reactions that is maladaptive to both emitter and the receiver.
- e) **Apneumone** : A chemical released by non living substance that is beneficial to the receiver but detrimental to other organism in the substance.

➤ **Uses of pheromones**

**Pest management with sex pheromones**

In insect pest management, sex pheromones are used in 2 ways

- I. Population survey
- II. Behaviour manipulation

**I. Population survey** : Synthetic sex pheromones of a large number of insect pests are used to know the population density in an area. This will help

- To know whether the pest population level has reached ETL for making pest management decisions
- To know the time of pest build up and the correct time for the adoption of control measures
- To know the suitable mode of control

**II. Behaviour manipulation**

The two strategies available to manipulate insect behaviour are

- 1. Stimulation of normal approach response
- 2. Disruption of chemical communication

**1. Stimulation of normal approach response** : The normal response of an insect to sex pheromone is attraction. This attraction is used to kill the insects in the following ways

- a) **Use of pheromone baited traps** : Pheromone baited traps are placed at suitable points. When the pests have gathered in large number they can be killed by insecticides. This technique is also called as male annihilation technique.
- b) **Orientation to a source of chemosterilant or insecticide** : By the use of pheromones, the insects could be guided to a sources of chemosterilant or insecticides to be sterilized or get killed.

- c) **Orientation to a combination of light and pheromone** : Pheromone and light are together used to attract a large number of nocturnal insects. The large number of males attracted can be killed by insecticides.
2. **Disruption of chemical communication** : Synthetic pheromones are introduced in the environment to mask the natural pheromone and this disrupt the normal pheromonal communication between pest species. This will results in failure to locate their mates and there by prevent mating.
- **In pest management pheromones are used for various purposes such as**
1. Monitoring
  2. Mass trapping
  3. Mating disruption

### 1. Monitoring

Pheromone baited traps are used to detect both the presence and density of the pest species. Insect populations can thus be estimated and new areas of infestation can be detected at a very early stage. The trap catches are correlated with weather parameters to develop forewarning models.

### 2. Mass trapping

A large number of pheromone baited traps are used in the field to capture males of the newly emerged moths and reduce the number of adults for mating. Modifications of mass trapping is lure and kill technique where instead of being trapped, the responding insects come in contact with an insecticide.

### 3. Mating disruption

Pheromones are used for suppressing mating by confusing male insects. Slow release pheromone formulations permeate the air with relatively high levels of pheromone so as to achieve sensory adaptation and habituation or provide numerous discrete point sources so as to mask trail following or to create false trail. With the disruption of mating, egg laying is prevented and thus the pest population level is reduced.

Ex : Mating disruption technique for the management of pink bollworm (*Pectiphora gossypiella*) in cotton by using PB Rope L (Sex pheromone based commercial product) dispensers @ 200 / ha

## 8.2 ADVANTAGES AND LIMITATIONS OF PHEROMONES

### ➤ Advantages

- Pheromones are non - pollutant and hence ecologically acceptable
- Minute quantities of pheromones are required to attract and kill a large number

of insects and hence they are economical

- Pheromones are species specific and hence pose no hazards to non-target organisms
- Pheromones offer an easy means to monitor the build up of pest populations
- This is a labour saving method since a large number of insects are brought from long distances right at the doorstep for being destroyed

➤ **Limitations**

- Sex pheromones can attract only one sex and the other sex could still be there to cause damage
- Most sex pheromones attract only adults while the larval stage causes the damage
- Pheromones are known for only a very few species of insect pests
- This method demands knowledge and expertise which are not within the reach of most of the farmers
- Quick results cannot be obtained with pheromones and hence they are not suitable as short term control measures
- Involves high cost to synthesize

### 8.3 TYPES AND FUNCTIONS OF INSECT HORMONES

➤ **Hormones**

These are the secretions of internal ductless glands, which regulate the growth and development of the insects.

**Types of insect hormones**

- |                     |                     |
|---------------------|---------------------|
| 1. Brain hormone    | 2. Ecdysone         |
| 3. Juvenile hormone | 4. Eclosion hormone |
| 5. Tanning hormone  |                     |

1. **Brain hormone**: The brain hormone or prothoracicotropic hormone (PTTH) is secreted by the neurosecretory cells of the brain and it activates the prothoracic glands to secrete ecdysone.
2. **Ecdysone**: This hormone is responsible for moulting in insects hence it is also called as moulting hormone. It is secreted by the prothoracic glands and it is necessary for each of the immature moults which must take place for insects

to grow. It is a mixture of  $\alpha$ -ecdysone and  $\beta$ -ecdysone.

3. **Juvenile hormone (JH)**: It is produced by corpora allata. Earlier it was named as neotenin due to its ability to keep the larvae in a permanently juvenile condition. In the presence of high titer of JH, a larvae moults into a larvae, while at a low titer of JH, it moults into a pupa. In the absence of JH, a pupa moults to become an adult. In adults it acts as gonadotropic hormone.
4. **Eclosion hormone**: It is released by the brain and control the process of eclosion in insects.
5. **Tanning hormone**: It is also known as bursicon. It is produced by the neuro secretory cells of the brain or abdominal ganglia and regulates the process of tanning and sclerotization of the new cuticle.

➤ **Hormonal control**

Since hormones regulate the development and metamorphosis, their synthetic analogues are called as insect growth regulators (IGRs). The analogues and antagonists of insect growth regulators such as juvenile hormones and ecdysones are used for pest control. The synthetic analogues of ecdysone are called ecdysoids and of JH are called juvenoids.

i) **Ecdysone as insecticide (Ecdysoids)**

High doses of  $\beta$ -ecdysone cause death of the insects due to toxic effect or they may undergo abnormal moulting. It inhibits DNA synthesis in epidermal cells, internal tissues and organs. It can be used as insecticide at all stages from newly hatched larvae to adults. They can be applied topically in various solvents and penetrate the cuticle and can also be used as fumigants. They can also be used as stomach poison and can be synergized by mixing with piperonyl butoxide. They are quite stable and act as anti ecdysone substances and block moulting.

About 40 different steroids have been isolated from the higher plants showing  $\alpha$ - and  $\beta$ -ecdysone activity and are called as phytoecdysones.

ii) **Juvenile hormones as insecticides (Juvenoids)**

Juvenoids kill the insects by

- By the antimetamorphic effect
- By the larvicidal effect
- By the ovidical effect
- By the diapause disrupting effect
- By the embryogenesis effect

JH treated immature insects fail to moult, die soon after ecdysis or fail to reproduce and develop intermediates between larvae and pupa, pupa and adult or larvae and adult. Young insects are killed by JH it can act on the last instar larvae during metamorphosis by inducing production of intermediates. In adults it functions as chemosterilant. About 500 substances have been isolated having JH activity and are used in pest control programmes.

Ex :

Methoprene (first commercial product) is used for the control of mosquitoes.

Fenoxycarb is used for the control of several fruit pests.

Pyriproxyfen is used against sucking pests.

Diofenolan is effective against lepidopteran pests.

NC - 196 is used against brown plant hopper of rice.

### iii) Antihormones as insecticides

Precocenes (I and II) obtained from bedding plant, *Ageratum houstonianum* function as anti - JH by destroying the corpora allata and prevent JH synthesis. Juvenile stages treated with these substances skip one or two of their larval instars to change into tiny precocious adults which will ultimately die. The advantage of anti hormones is that these are effective at any stage of the insect life cycle.

### iv) Chitin synthesis inhibitors as insecticides

Benzoylphenyl ureas compounds have the ability of inhibiting chitin synthesis in insects by blocking the enzyme chitin synthetase. The effects produced by these compounds on the insects are

- Disruption of moulting
- Failure to feed
- Failure of adults to escape from pupal skin
- Inhibition of hatching of eggs

Ex :

Di-flubenzuron (Dimilin) is used against gram pod borer, tobacco caterpillar, cabbage looper etc.

Teflubenzuron is effective against codling moth.

Buprofezin is effective against sucking pests.

## 8.4 ADVANTAGES AND LIMITATIONS OF HORMONAL CONTROL

### ➤ Advantages

- Hormonal insecticides are non-pollutant and hence ecologically acceptable
- These are non toxic to man, animals and plants
- These are highly biodegradable and so non persistent
- Minute quantities of are required and hence they are economical
- These are species specific and hence pose no hazards to non-target organisms
- These effect more than one aspect of an insect's development and physiology and hence effective against insects showing insecticidal resistance
- These are suitable to insects having several successive short cycles per season, sedentary and non migratory insects

### ➤ Limitations

- These are to be applied at specific time and specific stage
- Juvenoids affect only the last larval instar while the earlier instars could continue to cause damage
- Diapausing stages remain inaccessible to hormonal insecticides
- Slow in mode of action
- In case of failure there is no time to take emergency control measures
- These are unstable in environment
- Involves high cost to synthesize
- This method demands knowledge and expertise which are not within the reach of most of the farmers

## 8.5 CHEMOSTERILANTS

### ➤ Chemosterilants

The idea of controlling insects by sterilizing technique was first conceived by E.F. Knipling in 1937. Auderbach and Robson (1942) observed that mustard or nitrogen gas could produce sterility in the fruitfly, *Drosophila*.

#### **Definition**

The chemicals which deprive an ability of an insect species to reproduce an off spring is called chemosterilants.

The chemosterilant acts by

- Gametic disorder, chromosomal break or disruption of gametogenic cycle
- Oviposition may be prevented
- Deposited eggs may not hatch due to atresia formation
- Larvae may not pupate or pupae may not develop further due to lethal genetic mutations

The chemosterilants can be termed as the female chemosterilant whenever they disrupt the reproductive process of female insects. They are termed as male chemosterilants if they disrupt the male reproductive process and male –female chemosterilants to those chemicals which disrupt both male and female reproductive processes.

Chemosterilants can be grouped into

1. Alkylating agents
2. Anti - metabolites
3. Miscellaneous agents

### 1. Alkylating agents

They contain aziridinyl groups and cause alkylation. They act by inhibiting nucleic acid synthesis, inhibiting gonadal development and by mutagenic effects.

Alkylating agents which act as male –female chemosterilants are Apholate, Aphomide, Aphoxide (TEPA), Thio TEPA and Meta TEPA

### 2. Anti - metabolites

These are regarded as antagonistic structural analogues of the natural metabolites interfering with the synthesis of the nucleic acids. Ex: Fluorouracil, bromouracil, folic acid and colchicine.

### 3. Miscellaneous agents

These are non alkylating analogues of aziridinyl compounds. The male chemosterilants are HEMPA (hexamethylphosphoramide), HEMEL (Hexamethylamine) and Tretamine

### ➤ Method of application

- Chemosterilants can be applied as sprays and dusts
- They can be mixed with insecticides and can be applied
- They can be applied to places where the insects likely to rest or aggregate
- They can be sprayed on the natural food of insect or mixed with baits and kept in field



➤ **Advantages and disadvantages of chemosterilants****Advantages**

- Chemosterilants offer the possibility of 99% pest control
- They can be applied orally, topically, by injection, as dusts, sprays, fumigants
- They can be used for treating insect's habitats and resting places
- They offer means of sterilizing wild populations in the field itself which is not possible with irradiation
- It is cheaper than irradiation
- No resistance development

**Disadvantages**

- They are carcinogenic and phyto-toxic

**8.6 ANTIFEEDANTS**➤ **Antifeedants**

These are also called as feeding deterrents. Chemicals which are used to prevent the feeding of phyto-phagous and other insects without killing or repelling are termed as antifeedants.

**Some important examples of antifeedants**

| S.No. | Antifeedant                                                | Target insects                                              |
|-------|------------------------------------------------------------|-------------------------------------------------------------|
| 1     | Azadirachtin                                               | Desert locust and other insects                             |
| 2     | Baygon                                                     | Cotton boll weevil                                          |
| 3     | Brestan                                                    | Cut worms and potato tuber moth larvae                      |
| 4     | Chlorinated triphenyl methane and triphenylsulfonium salts | Phytophagous insects                                        |
| 5     | Organotins                                                 | Grasshoppers, <i>Agrotis</i> sp. and Colorado potato beetle |
| 6     | Phlorizin                                                  | <i>Myzus persicae</i>                                       |
| 7     | Pyrethrum                                                  | <i>Glossina</i> sp.                                         |
| 8     | Solanine                                                   | Potato leaf hopper                                          |
| 9     | Thio carbamates and phenyl carbamates                      | Beetles                                                     |
| 10    | Triazenes                                                  | Cockroaches and beetles                                     |

➤ **Mode of action**

Insect feeding comprises of three essential aspects, orientation on the plants, initial biting or feeding and sustained feeding. While the first two aspects are common to insects feeding on both antifeedant treated and untreated plants, sustained feeding is absent in antifeedant treated plants. Antifeedants interfere only with the gustatory stimulus by inhibiting gustatory receptors of the mouth region. Absence of right gustatory stimulus the insect fails to recognize the treated leaf as food.

➤ **Advantages and disadvantages of antifeedants****Advantages**

- These are specific to phytophagous insects and safe to beneficial insects
- They do not produce phytotoxicity or pollution
- Insects may move from crops to weeds

**Disadvantages**

- Only insects having chewing type of mouth parts (surface feeding insects) are affected sucking type of insects (internal feeders) are not affected
- New growth of the plants are not protected
- Dosage is very high
- Since insects are not immediately killed they may move to other parts or other plants

## 8.7 ATTRACTANTS

➤ **Attractants**

Chemicals which elicit oriented movements by insects towards their source are called insect attractants. They influence both gustatory and olfactory receptors

There are 4 types of attractants

- |                      |                       |
|----------------------|-----------------------|
| 1. Pheromones        | 2. Natural food lures |
| 3. Oviposition lures | 4. Poison baits       |

**1. Pheromones**

Substances released into the environment by insects and which cause specified reactions in individuals of the same or allied species are called as pheromone or ectohormones.

**2. Natural food lures**

These are chemicals present in plant and animal hosts that attract insects for feeding.

**Important examples of insect food lures**

| S.No. | Insect                    | Lure                               |
|-------|---------------------------|------------------------------------|
| 1     | <i>Aedes</i> sp.          | L lactic acid and carbon dioxide   |
| 2     | Bark beetle               | Terpenes                           |
| 3     | Carrot fly                | Phenylpropanoids from Umbelliferae |
| 4     | Chafer <i>Amphimallon</i> | Amblure                            |
| 5     | House fly                 | Sugar + molasses                   |
| 6     | Japanese beetle           | Geraniol                           |
| 7     | Mediterranean fruit fly   | Trimedlure                         |
| 8     | Melon fruit fly           | Cuelure                            |
| 9     | Onion fly                 | Propylmercaptan from onions        |
| 10    | Oriental fruit fly        | Methyl eugenol                     |
| 11    | Spotted cucumber beetle   | Cinnamaldehyde                     |
| 12    | Cabbage butterfly         | Sinigrin                           |

**3. Oviposition lures**

Chemicals that govern the selection of suitable sites for oviposition by the adult females.

Ex : p - methyl acetophenone attracts rice stem borer for oviposition

**4. Poison baits**

These are mixtures of food lures and insecticides

Ex :

Moistened bran base + molasses + insecticides for biting insects

Phosphorus + sweet syrup for cockroaches

Thallous sulphate + peanut butter for meat loving ants

Metaldehyde for garden snails and slugs

➤ **Advantages and disadvantages of attractants**

**Advantages**

- They do not kill the insects and therefore do not disrupt the ecosystem or food chain
- They are specific and safe to non target organisms
- They can be used for mass trapping

**Disadvantages**

- Insects can always find untreated hosts, so their number may not be affected
- They can not be used as sole control measure and can only be used as a component in IPM

## 8.8 REPELLENTS

➤ **Insect repellents**

Substances whose stimuli elicit avoiding reactions or chemicals that prevent insect damage to plants or animals by rendering them unattractive, unpalatable or offensive are called repellents.

There are 2 types of repellents

1. Physical repellents
2. Chemical repellents

**1. Physical repellents**

These include, waxes on leaf surfaces and oils on different parts repel various insects, and auditory type repellents like amplified sound producing devices used to repel mosquitoes.

**2. Chemical repellents**

These are chemicals that affect tactile, olfactory or gustatory receptors of insects and could be of plant origin or synthetic. The important repellents of plant origin are oil of citronella which is used as mosquito repellent and pyrethrum which is used as repellent against blood sucking insects.

**Important examples of synthetic repellents**

| S.No. | Repellents                          | Insect                   |
|-------|-------------------------------------|--------------------------|
| 1     | Benzyl benzoate                     | Mites                    |
| 2     | Bordeaux mixture                    | Foliage feeders          |
| 3     | Creosote or 4, 6 dinitro -o- cresol | Chich bugs               |
| 4     | Diacetyl phthalate                  | Cattle fleas             |
| 5     | Dimethyl phthalate                  | Mosquitoes               |
| 6     | N, N, diethyl m-toulamide (DEET)    | Mosquitoes, flies, fleas |
| 7     | Napahtlene balls                    | Cloth moths              |
| 8     | N - butylacetanilide                | Ticks, fleas             |
| 9     | Pentachlorophenol                   | Termites                 |
| 10    | Pine tar oil and diphenylamine      | Screw worm flies         |

**➤ Advantages and disadvantages of repellants****Advantages**

- They do not kill the insects and therefore do not disrupt the ecosystem or food chain
- They are specific and safe to non target organisms

**Disadvantages**

- They can not be used as sole control measure and can only be used as a component in IPM

**8.9 GENETIC CONTROL****➤ Genetic control**

Genetically manipulated insects are released among the wild populations to make the matings infructuous (eggs will be non viable or sterile) or to introduce lethal genes into the eggs of the females so that they do not develop beyond certain stage. This is also called as autocidal method.

The 3 methods of genetic control are

1. Sterilization (Sterile male technique and sterile insect technique)
2. Hybrid sterility
3. Cytoplasm incompatibility

**1. Sterilization****a) Sterile male technique**

In this method fully competitive sterile males are released in the natural populations. This will reduce reproductive potential of the natural populations in the same ratio as sterile to fertile.

**b) Sterile insect technique**

This method combines chemical and biological control methods. This technique involves the sterilization of both males and females of a portion of the wild population by chemo sterilants. The percentage sterilized can not reproduce and they reduce the reproductive capacity of a proportionate number of the fertile individuals in the population.

This method is called as sterile insect release method (SIRM) where in both males and females, are mass reared and sterilized in the laboratory and are release at every generation until the pest is eradicated or controlled. The advantage of SIRM is that each release of sterile insects achieves an increasing higher sterile to fertile ratio and thus become progressively more efficient compared to insecticides where in the number of insects killed in each generation remains constant.

**Consideration of SIRM****i) Time and place of release**

- The time and place of release should be such, as to allow good intermingling of the insects
- Adult emergence from release pupae should coincide with emergence of wild adults
- Releases should be done when wild populations are abundant

**ii) Sex of the insect to be released**

The choice of sex will depend on

- Availability of sex separation technique for the particular pest
- The insect used for release should not be a carrier of diseases
- Monogamous and polygamous nature of the insect (If female is monogamous and male polygamous, then the release of the sterilized male will be more suitable)

**iii) Integration with insecticidal control**

When the pest population is very high the insecticide control system should be integrated with sterile release system to obtain complete control.

**iv) Basic requirements of SIRM**

- Practical methods must be developed for rearing enough insects to over flood the natural populations
- Methods of inducing sterility must be available
- The method inducing sterility should not impair the sexual behavior of the insect
- Reasonably accurate estimates of the absolute numbers of the insects in the natural population are essential
- The released insects must be distributed so that they will be in reasonable spatial competition with the natural population for mating
- Information on the normal rate of increase of natural population increase
- The degree of infiltration of the target pest and its impact on the effectiveness of the technique must be considered
- The released insect must not cause damage to the crops, livestock and man

**Success of sterile insect technique**

- Eradication of screw worm fly, *Cochliomyia hominivorax* in island of Curacao. The males were sterilized by gamma radiation and were released @400 per square mile per week.
- Eradication of oriental fruit fly from the island of Tinian
- Suppression of population of Mediterranean fruit fly on the island of Hawaii
- Eradication of melon fruit fly on the island of Rota
- Eradication of field cockchafer in Switzerland
- Eradication of melon fruit fly and oriental fruit fly from Japan and Taiwan respectively

**2. Hybrid sterility**

In this method, sterility of insects is produced by other methods than irradiation and chemosterilants. In this method matings are induced between two closely related species or between two reproductively isolated varieties of a species under laboratory conditions. If such matings lead to fertilization, the hybrid individuals may die in the embryonic stage, in one of the pre adult stage or early in the adult stage. Alternatively, apparently normal adults produced may show partial or complete sterility in one or both the sexes.

**3. Cytoplasm incompatibility**

In this technique, a cross between two apparently conspecific population results in only partial embryonation in some ova. Spermatozoa enter the egg cytoplasm,

but no fusion occurs between the nuclei of spermatozoa and ova. This phenomenon of insemination with out fertilization is called cytoplasm incompatibility or incompatible insect technique.

➤ **Advantages and limitations of genetic control**

**Advantages**

- These methods are species specific and hence harmless to non target organisms
- They have no negative impact on the environment
- These methods are very efficient at low population density

**Limitations**

- These methods are complex and hence not user friendly to the farmers
- They are not effective at high population density or prolific breeders
- Lack of sufficient information about the behaviour and quality of sterile insects





# Integrated Pest Management

UNIT

9

## 9.1 CONCEPT AND PRINCIPLES OF INTEGRATED PEST MANAGEMENT (IPM)

### ■ Integrated Pest Management (IPM)

IPM is a system that in the context of the associated environment and the population dynamics of the pest species utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest populations at levels below those causing economic injury (FAO, 1972). In integrated pest management both crop and pest are seen as part of a dynamic agro-ecosystem.

IPM is a sustainable approach to managing pests by combining biological, cultural, mechanical and chemical tools in a way that minimizes economic, health and environmental risks.

The IPM concept is based on the principle that it is not necessary to eliminate all the pests but to suppress the pest population to a level at which these pests do not cause significant losses. An integrated strategy for crop pest management includes use of resistant varieties modifying agronomic practices to reduce pest incidence, biological control and other novel approaches for pest suppression and only need based judicious use of chemical pesticides.

#### ➤ Aims of IPM

- Keeping the pest numbers below harmful (economic threshold) level instead of their eradication
- Protecting and conserving the environment including the biodiversity
- In making plant protection feasible, safe and economical even for the smaller farmer
- Reduce the use of synthetic pesticides

#### ➤ Advantages of IPM

- More efficient and low priced method of control
- Does not upset the balance in nature

- Delays the development of resistance
- Minimizes the residue hazards of pesticides

➤ **Principles of IPM**

- Identification of key pests and beneficial organisms
- Defining the management unit, the Agro-ecosystem
- Development of management strategy
- Establishment of Economic thresholds (loss and risks)
- Development of assessment techniques
- Evolving description of predictive pest models

## 9.2 COMPONENTS OF IPM

The different components of IPM are

- |                      |                       |
|----------------------|-----------------------|
| • Monitoring         | • Resistant varieties |
| • Cultural control   | • Mechanical control  |
| • Bio - rationals    | • Biological control  |
| • Regulatory control | • Chemical control    |

**Monitoring** : Keep tracks of the pests and their potential damage. This provides knowledge about the current pests and crop situation and is helpful in selecting the best possible combinations of the pest management methods.

**Resistant varieties** : Cultivation of plant varieties which are less prone to pest attack. The resistant varieties reduce production cost. Use of Bt transgenic crops reduce the incidence of lepidopteran pests. Breeding for pest resistance is a continuous process. These are bred and selected when available in order to protect against key pests.

**Cultural control** : It includes crop production practices that make crop environment less susceptible to pests. Cultural methods such as deep ploughing and burning of crop residues, soil solarization, synchronous planting of crop fields, planting trap crops, intercropping, crop rotation, tillage, and use of pest free seeds and planting material are effective methods to reduce pest load. Cultural methods are based on pest biology and development.

**Mechanical control** : These are based on the knowledge of pest behaviour. Mechanical methods such as hand picking, installation of bird perches and mulching reduce the pest buildup. Physical methods of pest control involve manipulation of temperature, humidity, use of energy and sound.

**Bio - rationals :** Biorationals include plant products such as neem and bio-pesticides such as nuclear polyhedrosis virus and *Bacillus thuringiensis*. Non chemical methods for pest control, such as use of sex attractants or pheromones, insect growth regulators and repellants.

**Biological control :** These includes augmentation and conservation of natural enemies of pests such as insect predators, parasitoids, pathogen and weed feeders. In IPM programmes, native natural enemy population are conserved and non-native agents are released with utmost caution.

**Regulatory control :** Quarantine laws to prevent the entry of pest from other areas or other countries.

**Chemical control :** Pesticides are used to keep the pest population below economically damaging levels when the pests cannot be controlled by other means. It is applied ONLY when the pest's damaging capacity is nearing to the threshold.

➤ **Integrated Pest Management Strategy**

- While developing IPM strategy one has to select different components that are readily available, economical and applicable at field level
- To cater the needs for location specific cropping systems the suitable technologies should be developed by research workers from time to time
- The research findings that are practically implementable should be popularized by the Extension workers through education to farming community. Farmers have to be trained in scouting, diagnosis of pest infestation and arriving ETLs for need based chemical application in time
- Farmers should also be trained in selection of suitable pesticide, use of proper lethal dose and proper coverage of foliage to avoid risks of resistance, resurgence and residues. Farmers training is a continuous process and is an important integrated part for successful implementation of IPM
- An healthy, meaningful co-operation is very much needed from corporate pesticide industry to make IPM successful at farmers level. The pesticide industry should not wield enormous financial power and maintain market dominance against ecological and environmental safety.

## 9.3 IPM STRATEGIES FOR FIELD CROPS

### 1. IPM in rice

#### **Monitoring**

- Installation of pheromone traps @ 5 / ha for the monitoring of yellow stem borer
- Light traps for leaf hoppers and other photo-trophic insects

- Sweep nets besides visual observation to assess the population of insect pests and natural enemies

#### **Cultural practices**

- Growing pest resistant or moderately resistant varieties
- Use healthy seed and raising of healthy nursery
- Regulating 'N' applications to avoid nutritional resurgence of plant and leaf hoppers
- Transplanting at appropriate stage after removal of terminal part (2 to 4") of seedlings to reduce the chances of carrying and migration of immature stages of yellow stem borer and leaf folders
- Careful timing of planting
- Uprooting stubbles with deep ploughing soon after harvest
- Harvesting of crop to ground level to reduce the chances of yellow stem borer and gall midge build up
- Closer spacing should be avoided for management of brown plant hopper
- Irrigation management : Alternate wetting and drying of paddy fields for management of brown plant hopper
- Adopt planting with formation of alleys of 25 cm at intervals of 2 mts to provide good aeration and sunlight against brown plant hopper
- After harvest, fields should be thoroughly flooded with water and ploughed with disc or rotators to kill hibernating stages of insects

#### **Mechanical practices**

- Removing of grasses from the bunds and other alternate hosts
- Adoption of rope running to expose case worm and leaf folder larvae
- Collection and destruction of egg masses
- Lapping of tall varieties to prevent lodging and stem borer attack

#### **Behaviour control**

- Mass tapping of yellow stem borer by installation of pheromone traps @ 20 / ha after 20 days after transplanting. Lures containing 5 mg should be replaced 3 times at an interval of 20-25 days during the crop season

#### **Biological methods**

- Creating avenues for broad spectrum predators like spiders by maintaining shelters in and around rice fields and exploiting of potential predators like mirids, dragon flies and carabid beetles

### Augmentation

- Release of egg parasitoids, *Trichogramma japonicum* @ 50,000 / ha and *Trichogramma chilonis* @ 100,000 / ha at weekly intervals against yellow stem borer and leaf folder respectively
- Release of larval parasitoid, *Platygaster oryzae* against gall midge
- Release of *Cyrtorhinus lividipennis* @ 50 - 75 eggs per square meter at 10 days interval and 3 predatory spiders, *Lycosa pseudoannulata* per hill against brown plant hopper

### Chemical control

- Need based judicious and safe application of pesticides at recommended dose
- Nursery protection by applying carbofuran granules @ 40 kg / ha or phorate @ 12.5 kg / ha of nursery bed
- Application of recommended insecticides - endosulfan / monocrotophos / carbaryl / chlorpyrifos / quinalphos to reduce leaf folders and climbing cut worm as well as yellow stem borer
- Seedling root dip in 0.02 % chlorpyrifos against gall midge
- Need based application of triazophos or quinalphos against yellow stem borer

## 2. IPM in sorghum

- Use of light traps and pheromone traps for monitoring
- Deep summer ploughing to expose the resting stages of pests
- Growing of resistant varieties such as CHS - 7, CHS - 8 and IS - 5566 with higher seed rate for the management of shoot fly
- Growing resistant varieties such as SPH 837 against midge
- Trimming of bunds and uprooting and destruction of crop residues
- Destroy thrashed sorghum heads for minimizing the borer and midge attack
- Selection of healthy seed of less susceptible varieties
- Early planting to minimize the attack of shoot fly, midge and ear head bug damage
- Application of balanced nitrogen fertilizers
- Removal of dead hearts
- Collect and burn the infested panicles
- Uniform sowing of similar maturity sorghum cultivars over large areas
- Destruction of wild host plants including Johnson grass and sorghum volunteers

- Conserve natural enemies such as *Trichogramma*, *Apanteles*, lady bird beetles, *Chrysoperla* and spiders
- Growing of open-type panicle varieties against ear head bug
- Conserve reduviid bug and a lygaeid bugs
- Dusting of ear heads with endosulfan or carbaryl against midge
- Need based application of phorate or carbaryl or endosulfan

### 3. IPM in groundnut

- Undertake deep ploughing (8-10 inches) to expose resting stages of insects
- Deep burying of crop residues, destruction of crop debris by burning, removal of volunteer plants
- Follow recommended agronomic practices for land preparation, seed rate, spacing, fertilizer and irrigation management and keep the field free from weeds
- Use certified seeds of resistant or tolerant varieties
- Crop rotations with cotton, wheat, maize, jowar, onion and garlic
- Intercropping with castor against *Spodoptera litura*; soybean against leaf miner, and pearl millet for management of thrips
- Seed treatment with imidacloprid against sucking pests and chlorpyrifos or quinalphos against white grubs and termites
- Vegetative trapping of migratory larvae of red hairy caterpillars by keeping twigs of *Jatropha* or *Calotropis* and neem branches for trapping adult-white grubs
- Spray neem seed kernel extract (NSKE) @ 5 % or crude neem oil in teepol @ 2 % against defoliators and mites
- Spray *Bacillus thuringiensis* @ 1 - 1.5 kg / ha against *Spodoptera* and *Helicoverpa*
- Spray commercial formulation of nuclear polyhedrosis virus (NPV) for the management of *Spodoptera*, *Helicoverpa* and red hairy caterpillar @ 250 LE ( $6 \times 10^9$  / LE / ha)
- Release *Trichogramma chilonis* @ 50000 / ha, two times at 7 - 10 days interval followed by release of *Bracon hebetor* @ 5000/ha two times at 7 - 10 days against leaf miner and defoliators
- Install pheromone traps @ 10 traps / ha for *Spodoptera* and *Helicoverpa* and 25 traps/ha for leaf miner for monitoring
- Erect bird perches @ 10 - 12 / ha
- Need based application of chlorpyrifos EC 0.05 % or endosulfan 0.07 %

- Spray malathion 1.25 % or deltamethrin 0.04 % on the walls, floor and roof of the warehouses or godowns before storage and fumigation with aluminium phosphide @ 3 -5 tablets /ton of pods for the management of *Caryedon serratus*

#### 4. IPM in sugarcane

##### Monitoring

Monitoring of borers by the installation of pheromone traps @ 10 / ha

Installation of light traps for monitoring of white grubs

##### Cultural methods

- Deep summer ploughing to expose resting stages of insect pests
- Adopt proper crop rotation
- Grow resistance or tolerant varieties
- Select healthy setts for planting
- Sowing should be done timely
- Plating should be done in deep furrows (20 cm depth)
- Use well rotten farm yard manure to avoid damage by termites
- Avoid untimely high nitrogen fertilizers to minimize pyrilla, wooly aphid and stalk borer attack
- Irrigation at close intervals to minimize termites and early shoot borer
- Detrashing of canes in case of scale insects, mealy bug, wooly aphid and stalk bore attack
- Rouging of infested plants
- Propping the canes to prevent lodging and to reduce the damage by stalk borer and rodents
- Do not ratoon heavily affected crop
- Stripping of cane leaves minimizes the attack of scale insect

##### Mechanical methods

- Clipping of leaves bearing eggs masses of top borer, Gurdaspur borer and pyrilla
- Removal of dead hearts of early shoot borer and top borer
- Removal and destruction of infested canes
- Collection and destruction white grubs

**Biological methods**

- Conserve natural enemies such as *Trichogramma*, *Sturmiopsis*, *Isotima*, *Telenomus*, *Encarsia*, *Epiricania*, *Brumus*, *Menochilus*, *Chrysopa*, *Dipha*, syrphids and spiders
- Intercropping with cow pea and black gram to conserve natural enemies
- Avoid unwanted chemical sprays to conserve natural enemies
- Avoid unwanted burning to prevent destruction of natural enemies
- Soil incorporation of *Metarrhizium anisopliae*  $2.5 \times 10^{10}$  spores / m<sup>3</sup> for the management of white grub

**Augmentation**

- Release of egg parasitoids, *Trichogramma chilonis* @1,00, 000/ha against shoot borer
- Spray granulosis virus (GV) @ 250 LE/ha against shoot borer
- Release of *Pharoscymus horni* @ 1500 adults beetles or grubs against scale insect
- Release of parasitoid, *Dipha aphidvora* for the management of wooly aphid
- Release of parasitoid, *Epiricania melanoleuca* @ 4000-5000 cocoons or 4-5 lakh eggs / ha for the management of pyrilla

**Chemical control**

- Need based judicious and safe application of insecticides
- Application of chlorpyrifos at the time of planting for the management of termites, white grubs and early shoot borer
- Application of phorate or carbofuran granules along the furrows for the control of top shoot borer
- Application of metasystox or dimethoate for the management of sucking pests
- Setting of bromodialone baits for the management of rodents

**5. IPM in cotton****Monitoring**

- Use pheromone traps for monitoring of bollworms such as American, spotted and pink bollworms and *Spodoptera*, at a distance of 50 m @ 5 traps/ha.
- Set up yellow pan / sticky traps for monitoring whitefly and aphids @ 25 yellow pans / sticky traps / ha.



**Pre - sowing stage**

- Deep ploughing in summer
- Removal of alternate hosts
- Avoid cotton after cotton
- Adopt crop rotation
- Remove and destroy crop residues by burning
- Trap cropping with okra, castor, marigold, *Nicotiana rustica*, and insect feeding on these, should be periodically removed or killed
- Inter-cropping with mung bean, soybean, groundnut, ragi, maize, cowpea and onion reduces the infestation of boll worms. Intercropping with wild brinjal reduces the whitefly incidence.
- Intercropping with cowpea help to colonize the bio control fauna such as lady bird beetles, *Chrysoperla* etc.
- Acid delinting of seeds should be done before sowing (with commercial sulphuric acid @ 0.1 l/kg of seed ) and fumigate with celphos @ 3g/cum for 48 hrs and air dried

**Sowing stage**

- Grow tolerant / resistant varieties of key pests of that area
- In case of severe leaf hoppers infestation areas select varieties such as L-604, LRA 5166, L - 603, Savitha, Narasimha (NA 1375), NHH 44, H 8, NHH 390 and Lam Hybrid
- In case of whitefly endemic areas select varieties such as LK 861, LPS 141 (Kanchana) and NA 1280
- Use certified seeds
- Early sowing
- Seed treatment with imidacloprid for the management of sucking insect pests
- Adopt proper spacing and maintain plant population.
- Adopt judicious fertilizer and water management
- Avoid excessive use of nitrogenous fertilizers
- Maintain weed - free crop for at least 8 - 9 weeks after sowing till canopy starts closing by timely inter- cultivation
- Use Bt cotton varieties against *Helicoverpa armigera*

**Vegetative stage**

- Gap filling and thinning

- Inter culture and hand weeding of weeds
- Check population on trap crops and inter crops
- Release of *Trichogramma* egg parasite @ 50,000 / ha and *Chrysopa* egg larval predator @ 10000 / ha, should be done as soon as the first brood of boll worms is noticed
- Topping of cotton plants when maximum egg laying of *Helicoverpa armigera* is noticed
- Application of *Ha* - NPV @ 250 LE / ha or Bt formulation @ 1.5 kg/ha or neem seed kernel extract (5%) in synchrony with early larvae of *Helicoverpa*.
- Spray neem oil formulation to manage whitefly initially
- If pest persists spray recommended insecticides
- Crushing of larvae in the shoots mechanically

#### **Flowering stage**

- Continue inter culturing and hand weeding of weeds
- Management of trap crops and inter crops
- Release *Chrysoperla* @ 10,000 / ha for sucking insect pests
- Use pheromone traps and change lures for bollworms
- Management of population of bollworms in trap crops
- Release of *Trichogramma* @ 1.5 lac / ha for bollworms
- Use of light traps (one light trap / 5 acres) and bird perches (10 / acre).
- Hand picking of egg masses and young larva of tobacco caterpillar
- Spray triazophos / acephate / acetamiprid for the management of whitefly
- Destroy plants affected with cotton leaf curly virus (CLCV)
- Spray recommended chemical for vector control

#### **Fruiting stage**

- Collection and destruction of damaged floral bodies
- Collection of grown up larvae and destroy them
- Spray of *Ha* - NPV @ 250 - 500 LE / ha
- Use neem products
- Removal of terminals is to be done
- Spray *Sl* - NPV in evening hours against tobacco caterpillar
- Spray recommended insecticides against boll worms

**Boll opening stage**

- Apply need based recommended insecticides
- Do not extend the crop period
- Use monitoring device
- Use recommended acaricides for mites
- Destruction of CLCV infected plants
- Spot application of chemicals and need based application of monocrotophos / triazophos / acephate / fenvalerate

**Management strategy for pink boll worm in cotton**

- Avoid staggered sowing in an area and take up timely sowings
- Use acid delinted seed only
- Keep the crop free from weeds
- Monitor the pest build up with field scouting and pheromone traps
- Destroy pink boll worm larvae in rosette flowers and also through periodical removal of dropped squares, dried flowers and pre-matured bolls, to suppress pest population in the initial stage
- Avoid ratooning or summer cotton
- Promptly remove and destroy cotton stubbles to prevent carry over of pest to next season
- Restrict the movement of cotton seed from other areas.
- Need based use of insecticides
- Burn the stained kapas regularly
- Use PB Rope L (Sex pheromone based commercial product) dispensers @ 200/ha for the management of pink bollworm (*Pectiphora gossypiella*) by mating disruption technique

**6. IPM in pigeon pea**

**Monitoring**

- Pest monitoring through light trap
- Install pheromone traps at a distance of 50 m @ 5 traps/ha. For monitoring of gram pod borer

**Pre sowing**

- Apply FYM or neem cake

- Synchronize sowing with a single variety in a village / area
- Inter crop with sorghum for reducing *Helicoverpa armigera*
- Early planting for avoiding peak infestation period of *H. armigera* on short duration pigeonpea
- Resistant / tolerant varieties
- Cultivating early maturing varieties
- Planting of castor or tall sorghum/maize varieties on borders for conserving natural enemies. These plants also function as live perches for predatory birds
- Plant short stature crop like cowpea, mungbean, urdbean, fodder soybean etc. in 1 m wide band after 8-10 rows of pigeonpea

#### **Sowing stage**

- Growing trap crop like marigold on the borders and in between rows as inter crop. Their flowers shall attract oviposition by gram pod borer which can then be plucked and disposed
- Ridge planting + cover crops like soybean or cowpea
- Soil treatment with carbofuran granule @ 8 kg a.i. / ha at planting or seed treatment

#### **Vegetative stage**

- Inter - culture and hand weeding for keeping the crop, weed free for 6-8 weeks
- Hand picking, jarring on cloth or in bags is effective in a limited way in small areas
- Conservation of predatory spiders and wasps etc.
- Installation of bird perches for the predatory birds

#### **Flowering and fruiting stage**

- Removal and destruction of sterility mosaic affected plants
- Collection and destruction of caterpillars
- Conservation of predatory spiders and wasps etc.
- Installation of bird perches for the predatory birds
- Application of *Ha* - NPV @ 250 LE per ha.
- Need based spray of B.t @ 1.0 kg / ha
- Spray of NSKE 5% at pre - flowering stage 3 times at 15 days interval
- Need based spray of 0.07 % endsulfan or 0.04 % monocrotophos or chlorpyrifos 20 EC @ 3.5 ml. / lit.

### **Management of pod borer complex**

- ETL 10 % affected parts
- Deep summer ploughing in 2 - 3 years to eliminate quiescent pupa
- Early sowing and short duration varieties
- Avoid closer plant spacing
- Grow tall sorghum to serve as biological bird perches
- Collect and destroy larvae and adults to the extent possible
- Install pheromone traps at a distance of 50 m @ 5 traps / ha for monitoring
- Install bird perches @ 50 / ha.
- Setting of light traps (1 light trap / 5 acre) to kill moth population.
- Releasing of *Trichogramma chilonis* at weekly intervals @ 1.5 lakh / ha / week for four times
- Conserve green lacewing, predatory stink bugs, spider and ants
- Application of NPV 250 LE /ha with teepol 0.1% and Jaggery 0.5% thrice at 10 – 15 days interval commencing from flowering stage when the larvae are in early stage
- Spray of Bt @ 1.5 kg /ha
- Spray NSKE 5% twice followed by triazophos 0.05 %.
- Need based spray of endosulfan 35 EC @ 1000 ml / ha. or quinalphos 25 EC @ 1000 ml / ha.

### ➤ **Management of mealy bugs**

#### **Monitoring**

- Regular monitoring of the crop for mealy bugs infestation and its natural enemies

#### **Cultural and Mechanical**

- Monitoring and scouting to detect early presence of the mealy bugs
- Pruning of infested branches and burning them
- Removal and burning of crop residues
- Removal of weeds / alternate host plants such as hibiscus, parthenium etc.
- Avoiding the movement of planting material from infested areas to other areas
- Avoiding flood irrigation
- Prevention of the movement of ants and destruction of already existing ant colonies

- Sanitization of farm equipment before moving it to the uninfested crop
- Application of sticky bands or alkathene sheet or a band of insecticide on arms or on main stem to prevent movement of crawlers

#### **Biological control**

- Conservation of these natural enemies such as *Cryptolaemus montrouzieri*, ladybird beetles, lacewings, hover flies, *Scymnus* sp. and certain hymenopteran and dipteran parasitoids
- Conservation of lepidopteran predator, *Spalgis epius* (Lycaenidae) which feeds efficiently on the ovisacs, nymphs and adults

#### **Chemical control**

- Locate ant colonies and destroy them with drenching of chlorpyrifos 20 EC @ 2.0 ml / litre of water.
- Spot application of insecticide immediately after noticing mealybug on some plants in the crop field.
- Apply recommended chemical insecticides such as profenophos 50 EC (2 ml / litre), chlorpyrifos 20 EC (2ml/litre), buprofezin 25 EC (2 ml / litre), dimethoate 30 EC (2 ml / litre), thiomethoxam 25 WG (0.6 g / litre), imidacloprid 17.8 SL (0.6 ml / litre)
- Avoid repeating the use of the same chemical insecticide to avoid development of resistance
- Drenching soil with chlorpyrifos around the collar region of the plant to prevent movement of crawlers of mealybugs and ants

## **9.4 IPM STRATEGIES FOR HORTICULTURAL CROPS**

### **1. IPM in brinjal**

- Deep summer ploughing
- Erection of bird perches @ 10 / acre
- Installation of delta traps and yellow sticky traps for leaf hoppers and whiteflies
- Installation of pheromone traps @ 10 / ha for monitoring and mass trapping of *Leucinodes orbonalis*
- Soil application of neem cake @ 250 kg / ha along the plant rows
- Three sprays of neem seed kernel extract (NSKE) @ 5 % against sucking pests

- Six releases of egg parasite, *Trichogramma brasiliensis* @ 1 lakh / ha for shoot and fruit borer
- Clipping of borer damaged shoots
- Collection and destruction of damaged fruits
- Collection and destruction of egg masses, larvae and adults of hadda beetle
- Rouged out little leaf of brinjal affected plants
- Need based spray of imidacloprid (leafhoppers) and indoxacarb (fruit borer)

## 2. IPM in okra

- Use of popular Yellow Vein Mosaic (YVM) resistant hybrids such as Sun- 40 and Makhmali
- Sowing of sorghum / maize as a border crop
- Yellow sticky polythene traps smeared with castor oil and delta traps for whiteflies
- Erection of bird perches @ 10 / acre
- Installation of pheromone traps @ 10 / ha for monitoring of *Earias vittella*
- Three sprays of NSKE @ 5 % for leaf hopper, whiteflies and mites
- Five releases of *Trichogramma chilonis* starting from 42 days after sowing at weekly intervals
- YVM affected plants should be removed
- Borer affected shoots rouged out from time to time
- Need based spray of imidacloprid, cypermethrin, chlorpyrifos and fenvalerate

## 3. IPM in cabbage and cauliflower

- Soil solarization / raised bed sowing
- Seed treatment with imidacloprid @ 5g / kg
- Sowing of two lines of mustard after 25 rows of cauliflower
- Grow bold seeded mustard as a trap crop against diamond back moth
- Installation of yellow sticky traps for trapping winged aphids
- Erection of pheromone traps @ 10 / ha for *Spodoptera litura* and diamond back moth
- Hand picking of egg masses / bigger larvae / plucking of leaves infested with bunch of neonate larvae
- Mechanical removal of aphid infested twigs from the field

- Periodical weeding helps in reducing building up of painted bug population
- Conserve natural enemies such as *Trichogramma*, *Bracon*, *Telonomus* etc.,
- Need based application of NSKE 5%, *Sl*- NPV @250LE/ha early in the season when infestation level is low
- Need based spray of novaluron / spinosad against *S. litura*
- Apply malathion 5 % dust @ 25 kg / ha if needed

#### 4. IPM in coconut

- Cutting and burning of the dead and dried palms
- Mass collection of rhinoceros beetles from crowns with hooks
- Close the openings on the trunk with clay or cement to check red palm weevil attack
- Installation of pheromone traps for mass trapping of red palm weevil and rhinoceros beetles @ 20 / ha
- Removal of potential breeding sites of rhinoceros beetle and treating them with *Metarrhizium anisopliae*
- Setting of light traps
- Spray of *Oryctes* non occluded virus and release of natural enemy, *Platyeris laevicollis* against rhinoceros beetles
- Inundative release of parasitoids, *Goniozus nephantidis* and *Bracon brevicornis* at 300 and 4500 per ha, pupal parasitoid *Trichospilus pupivora*, and *Spoggosia bezziana* against black headed caterpillar
- Setting of molasses or toddy traps for mass trapping of red palm weevil
- Spray of *Metarrhizium anisopliae* @  $5 \times 10^{10}$  spores/ha against rhinoceros beetles
- Root feeding with monocrotophos
- Treat the manure pits with carbaryl dust
- Combination treatment containing neem formulation (5 ml) with entomopathogenic fungus, *Hirsutella thompsonii* (5 g) per tree for the management of mites
- Need based spray of sulphur 80 % SP @ 6 grams / litre against mites

#### 5. IPM in banana

- Monitoring of banana corm weevil with pseudostem trap and with pheromone traps
- Remove and destroy the post harvest residues



- Crop should be free from weeds
- Deep ploughing to expose soil inhabiting stages of insects
- Growing banana after banana should be avoided
- Select healthy suckers from infestation free areas
- Sucker treatment
- Drenching of soil with chlorpyrifos before planting
- Clean cultivation
- Removal of pseudostems below ground level
- Trimming the rhizome
- Soil incorporation of carbofuran granules against corm weevil
- Swabbing the pseudostem with monocrotophos
- Stem injection with monocrotophos

#### 6. IPM in citrus

- Destruction of weed hosts
- Smoking below the trees to scare away the fruit sucking moths
- Bagging of fruits with polythene or paper cover to avoid damage by fruit sucking moths
- Destruction of the fallen and decaying fruits
- Hand picking of various stages of the pest and destruction of the same
- Field release of *Mallada boninensis* @ 30 larvae/ tree against blackfly, psylla, leaf miner, aphids and mealy bugs
- Release of parasitoids such as *Encarsia sp.* on blackfly, *Tamarixia radiata* on psylla and *Citrostichus phyllocnistoides* and *Cirrospilus quadristriatus* on leaf miner
- Release of predators such as chrysopid, *Mallada boninensis* and the coccinellid, *Serangium parcesetosum*
- Need based spray of dicofol @ 1.5 ml or wettable sulphur @ 3 g against mites
- Need based spray of monocrotophos @ 1.5 ml or quinalphos @ 2 ml or dimethoate @ 1.5 ml or fenvalerate 1 ml/L or imidacloprid

**Varieties resistant to insect pests in various crops**

| <b>Crop</b> | <b>Insect pest</b>    | <b>Resistant or Promising varieties</b>                                                                                                                                |
|-------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rice        | BPH                   | KRH-2, Jyothi (PTB 39), Bhadra, Manasarovar, Bharathidasan, Neela, Udaya, Sonasali, Vajram, Chaitanya, Nagarjuna, IET 7575, Chandana, Krishnaveni and Kartika          |
|             | WBPH                  | HKR 120, HKR 126, Tangner and IET 8116                                                                                                                                 |
|             | Gall Midge            | Kavya Jyothi (PTB 39), Shakti, Vikram, Surekha, Phalguna, Varalu, Asha, Samridhi, Lalat , Abhaya, Shaktiman, Ratnagiri 3, Mahamaya, Panchami, Pavithra and R 636 - 405 |
|             | Stem borer            | Ratna, Vikas, Saket and Sasyasree                                                                                                                                      |
|             | GLH                   | IR 20, ADT 38, Vikramarya, Vani, Lalat and Nidhi                                                                                                                       |
|             | Multiple Resistance   | Suraksha, Shaktiman and Triguna                                                                                                                                        |
| Maize       | Maize stem borer      | Him 129, Ganga 4, 5, 7 and 9, Ganga Safed 2, Deccan 103, Ageti, Kanchan, Kundan                                                                                        |
|             | Pink Stem borer       | Deccan 101, Deccan 103                                                                                                                                                 |
|             | Shoot fly             | DMR 5, NCD, VC 80                                                                                                                                                      |
| Sorghum     | Shoot fly             | M 35 - 1, Swati, SPV 491, Phule Yashoda                                                                                                                                |
|             | Midge                 | ICSV 745, ICSV 197, AF 28, DJ 6514                                                                                                                                     |
|             | Head bug              | Chencholam, IS 17610, IS 17645, CSM 388                                                                                                                                |
|             | Spotted stem borer    | E 302, E3030, ICSV 700, ICSV 705                                                                                                                                       |
| Cotton      | American bollworm     | L 1245, Sujata, LK 861, Abadhita                                                                                                                                       |
|             | Pink bollworm         | G27, LD 135, Lohit Abadhita, MCU 7, Sujata, Digvijay, Sanguineum                                                                                                       |
|             | Spotted bollworm      | L 1245, BCS 10, BCS 10-75, G 27, Sanguineum                                                                                                                            |
|             | Leafhoppers           | Khandwa, Badnawar, MCU 5, Krishna, Mahalakshmi, Sujay, sanguineum, Eknath                                                                                              |
|             | White fly             | Amravathi , Kanchan, Supriya, LK 861, LPS 141                                                                                                                          |
| Brinjal     | Shoot and fruit borer | Chaklasi Doli, Doli 5, Pusa Purple long, Pusa Purple Round, Pant Samrat, SM 67, SM 68                                                                                  |
|             | Hadda beetle          | Arka Kusumkar, Arka Shirish, Vijay, Hisar Sel 1-4                                                                                                                      |
|             | Leafhoppers           | Chaklasi Doli, Doli 5, Pusa Purple                                                                                                                                     |
| Okra        | Shoot and fruit borer | AE 57, PMS 8, Parkins long green, Karnual special                                                                                                                      |

|                      |                                                                                 |                                                                                                                                                                                                        |
|----------------------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tomato               | Fruit borer                                                                     | BT 1, T 32, T 27, Punjab Kesari, Punjab Chuhashu, Pant Bahar, Azad Pusa Hybrid 4                                                                                                                       |
| Sugarcane            | Top borer<br>Stalk borer<br>Inter nodal borer<br>Sugarcane scale<br>White grubs | Co 7224, Co 67, Co 1158, CoP 9302<br>Co 7302, Co 5767<br>Co 6806, Co 62175, Co 975, Co 77-1<br>CoS 671, Co 8014, Co 62174, Co 1132, Co 611, Co 6907<br>Co 6304, Co 1158, Co 5510                       |
| Groundnut            | Leaf miner<br>Leafhoppers<br><br>Thrips<br><br><i>Spodoptera litura</i>         | BG-2, M 13, ICGV 86031, ICG 57<br>Girnar 1, MH-2, MH-4, AK-159, M 13, NcAc 2230, ICG 5043, ICG 5049<br>Girnar 1, MH-2, MH-4, AK-159, M 13, Robut 33-1, ICG 5043, ICG 5044<br>BG-2, ICGV 86031, FRDS 10 |
| Rapeseed and mustard | Mustard aphid                                                                   | <i>Brassica juncea</i> – PBR 91, Pusa Jai Kisan, Laha 101, Pusa kalyani, RLM 84<br><i>B. Napus</i> – Guilliver, GSA, Regent, GS 47, V 3<br><i>B. Campestris</i> – Tora, CDA-Span, Sariahi              |
| Soybean              | Leaf miner                                                                      | PI 227687, Nimsoy, PL 507, EC 18687                                                                                                                                                                    |
| Chickpea             | Pod borer                                                                       | C 235, Pant G 114, Anupam, JG 74, ICCV 10, ICCV 7, Dulia, Pusa 261, Vijay, Vishal                                                                                                                      |
| Pigeonpea            | Pod borer<br><br>Pod fly                                                        | T21, Bori, BDN 2, ICPL 332 (Abhaya), MA2, Bahar, ICPL 84060<br>ICP 10531-El, ICP 7941 El, ICP 7176-5, KM                                                                                               |
| Potato               | Tuber moth                                                                      | QB 1A 21-29                                                                                                                                                                                            |
| Tobacco              | Aphid<br>Leaf caterpillar<br>Stem borer                                         | Jamaica, Cuban, Fransons, Sumatra<br>GT 4, DWFC<br>SBR 1, SBR 2                                                                                                                                        |
| Apple                | Wooly aphid                                                                     | Golden delicious, Northern spy and Norton stocks 778, 779                                                                                                                                              |

**9.5 Economic Threshold Levels (ETLs) of major insect pests of various crops**

| Crop      | Insect pest                                                   | ETL (s)                                                                                   |
|-----------|---------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Rice      | Brown planthopper, <i>Nilaparvata lugens</i> (Stal)           | 5 - 10 hoppers / hill                                                                     |
|           | Gall midge, <i>Orseolia oryzae</i> (Wood - Mason)             | 1 gall / m <sup>2</sup> in endemic areas or<br>5 - 10% silver shoots in non-endemic areas |
|           | Green leafhopper, <i>Nephotettix</i> spp.                     | 2 insects / hill in tungro endemic areas, 20 - 30 insects / hill tungro endemic areas     |
|           | Gundhi bug, <i>Leptocorisa acuta</i> (Thunberg)               | 1 nymph / adult / hill                                                                    |
|           | Hispa, <i>Dicladispa armigera</i> (Olivier)                   | 1 adult or 1 - 2 damaged leaves / hill                                                    |
|           | Leaf folder, <i>Cnaphalocrocis medinalis</i> (Guenee)         | 10 % folded leaves                                                                        |
|           | Whitebacked planthopper, <i>Sogatella furcifera</i> (Horvath) | 5 - 10 hopper / hill                                                                      |
| Maize     | Yellow stem borer, <i>Scirpophaga incertulas</i> (Walker)     | 5 % deadhearts or white ears /<br>1 egg mass / m <sup>2</sup>                             |
|           | Earworm, <i>Helicoverpa armigera</i> (Hubner)                 | 20 - 30 % damage to cobs                                                                  |
|           | Shoot fly, <i>Atherigona</i> spp.                             | 5-10% deadhearts                                                                          |
| Sorghum   | Stem borer, <i>Chilo partellus</i> (Swinhoe)                  | 5-10% infestation                                                                         |
|           | Midge, <i>Contarinia sorghicola</i> (Coquillett)              | 1 adult / panicle<br>15 % deadhearts                                                      |
|           | Shoot fly, <i>Atherigona soccata</i> Rondani                  | 5 % deadhearts                                                                            |
|           | Stem borer, <i>Chilo partellus</i>                            | 15% deadhearts                                                                            |
|           | Shoot fly, <i>Atherigona soccata</i> Rondani                  | 5% deadhearts                                                                             |
| Chickpea  | Stem borer, <i>Chilo partellus</i>                            | 5% deadhearts                                                                             |
|           | Cutworm, <i>Agrotis ipsilon</i> (Hufnagel)                    | 5% plant mortality                                                                        |
| Pigeonpea | Pod borer, <i>Helicoverpa armigera</i>                        | 3 eggs or 2 small larvae/plant                                                            |
|           | Leaf Webber, <i>Maruca vitrata</i> (Geyer)                    | 5 webs / plant                                                                            |
|           | Pod borer, <i>Helicoverpa armigera</i> (Hubner)               | 5 eggs or 3 small larvae/plant                                                            |
|           | Pod fly, <i>Melanagromyza obtuse</i> (Malloch)                | Presence of 5% oviposition on pod basis                                                   |
|           | Pod sucking bug, <i>Clavigralla gibbosa</i>                   | 1 egg mass / plant                                                                        |

|                         |                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                             |
|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Soybean                 | Girdle beetle, <i>Obereopsis brevis</i> (Gahan)<br>Hairy caterpillar, <i>Spilosoma obliqua</i> Walker<br>Stem fly, <i>Ophiomyia phaseoli</i> (Tryon)                                                                                                                                | 5 % incidence<br>5 larvae / meter row<br>5 % plant infestation                                                                                                                                                                                                                                                                              |
| Groundnut               | Aphid, <i>Aphis craccivora</i> Koch<br><br>Jassids, <i>Balclutha hortensis</i> L.<br><br>Leaf miner, <i>Aproaerema modicella</i> (Deventer)<br><br>Thrips, <i>Scirtothrips dorsalis</i> hood<br><br>Tobacco caterpillar, <i>Spodoptera litura</i> (Fabricius) and other defoliators | 5 - 10 aphids / terminal at seedling stage<br>5 to 10 adults / plant up to 30 days after germination<br>5 mines / plant at 30 days of crop age, 10 mines / plant up to 45 days after emergence, 15 mines / plant up to 50 days after emergence<br>5 thrips / terminal at seedling stage<br>20 - 25 % defoliation at 40 days after emergence |
| Rapeseed                | Mustard aphid, <i>Lipaphis erysimi</i> (Kaltenbach)                                                                                                                                                                                                                                 | 50 - 60 aphids / 10 cm terminal portion of central shoot or when plants infested by aphids reach 40 - 50 %                                                                                                                                                                                                                                  |
| Sesame                  | Leaf webber, <i>Antigastra catalaunalis</i> (Duponchel)                                                                                                                                                                                                                             | 2 - 5 webs / plant                                                                                                                                                                                                                                                                                                                          |
| Sunflower               | Head borer, <i>Helicoverpa armigera</i> (Hubner)                                                                                                                                                                                                                                    | One larva / head                                                                                                                                                                                                                                                                                                                            |
| Brinjal                 | Fruit and stem borer, <i>Leucinodes orbonalis</i> Guenee                                                                                                                                                                                                                            | 1 - 5 % shoot / fruit infestation                                                                                                                                                                                                                                                                                                           |
| Cabbage and cauliflower | Diamondback moth, <i>Plutella xylostella</i> (Linnaeus)<br><br>Tobacco caterpillar, <i>Spodoptera litura</i> (Fabricius)                                                                                                                                                            | 1 - 5 % incidence<br><br>1 - 5 % incidence                                                                                                                                                                                                                                                                                                  |
| Tomato                  | Fruitworm, <i>Helicoverpa armigera</i> (Hubner)                                                                                                                                                                                                                                     | 1 - 5 % fruit damage                                                                                                                                                                                                                                                                                                                        |

**Economic Threshold Levels (ETLs) of major insect pests of cotton**

| S.No. | Insect pest                                               | ETL                                                                                                                               |
|-------|-----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| 1.    | American bollworm, <i>Helicoverpa armigera</i> (Hubner)   | 5 - 10 % boll infestation                                                                                                         |
| 2.    | Aphid, <i>Aphis gossypii</i> Glover                       | Appearance of honeydew on 50% of plants                                                                                           |
| 3.    | Jassid, <i>Amrasca biguttula</i> (Ishida)                 | 1 - 2 nymphs / leaf or when second grade injury symptoms (Yellowing and curling at margins of leaves) appear in 50% of the plants |
| 4.    | Pink bollworm, <i>Pectinophora gossypiella</i> (Saunders) | 5 - 10 % boll infestation                                                                                                         |
| 5.    | Spotted bollworm, <i>Earias insulana</i> (Boisduval)      | 5 - 10 % boll infestation                                                                                                         |
| 6.    | Whitefly, <i>Bemisia tabaci</i> (Gennadius)               | 8 - 10 adults / leaf or leaf stickiness due to deposition of honeydew on 50% of plants                                            |

**Economic Threshold Levels (ETLs) of major insect pests of sugarcane**

| S.No. | Insect pest                                                  | ETL                                  |
|-------|--------------------------------------------------------------|--------------------------------------|
| 1     | Internode borer, <i>Chilo sacchariphagus indicus</i> (Kapur) | 10 % shoot damage at tillering phase |
| 2.    | Pyrilla, <i>Pyrilla perpusilla</i> (Walker)                  | 3 - 5 nymphs or adults / leaf        |
| 3.    | Scale insect, <i>Melanaspis glomerata</i> (Green)            | 20 - 30 % canes with scale incidence |
| 4.    | Shoot borer, <i>Chilo infuscatellus</i> Snellen              | 15 % incidence                       |
| 5.    | Top borer, <i>Scirpophaga nivella</i> (Fabricius)            | 5 % damage of terminal portion       |

**Economic Threshold Levels (ETLs) of major insect pests of fruit crops**

| Crop   | Insect pest                                                                                                                                                           | ETL                                                                                  |
|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Apple  | Codling moth, <i>Cydia pomonella</i> (Linnaeus)<br>Phytophagous mites, <i>Panonychus ulmi</i> (Koch)<br>San Jose scale, <i>Quadraspidiotus perniciosus</i> (Comstock) | 1 - 2 % incidence<br>5 - 10 % foliage infestation<br>Appearance of pest in 5 % trees |
| Grapes | Flea beetle, <i>Scelodonta stricollis</i> (Most)<br>Mealy bug, <i>Maconellicoccus hirsutus</i> (Green)<br>Thrips, <i>Retithrips syriacus</i> (Mayet)                  | 2 % foliar damage<br>1 % bunch infestation<br>5 thrips / young leaf                  |
| Mango  | Leaf webber, <i>Orthaga exvinacea</i><br>Mango hopper, <i>Amritodes atkinsoni</i> (Lethiery)<br>Stem borer, <i>Batocera refomaculata</i> De Geer                      | 10 % incidence<br>5 adults / panicle<br>Appearance of pest                           |
| Ber    | Ber fruit fly, <i>Carpomyia vesuviana</i> Costa                                                                                                                       | 1 - 2 % incidence                                                                    |
| Citrus | Citrus caterpillar, <i>Papilio demoleus</i> (Linnaeus)                                                                                                                | 20 - 30 % foliar damage                                                              |

**9.6 CONCEPT OF DAMAGE LEVELS**

- **Economic damage** : The amount of injury which will justify the cost of artificial control measures.

Injury : It is the effect of pest activity on host physiology that is usually harmful.

Damage : It is measurable loss of yield quantity or quality

- **Gain threshold**

Stone and Pedigo found it useful to describe the term economic damage as loss of marketable produce and called it gain threshold

$$\text{Gain threshold} = \text{Cost of management (Rs./ha)} / \text{Value of commodity (Rs./kg)} \\ = \text{kg/ha}$$

- **Damage boundary** : It is the lowest level of injury where damage can be measured.
- **Economic Injury Level (EIL)** : The concept of EIL was introduced by Stern *et al.* (1959). The lowest number of insects that will cause economic damage is referred to as economic injury level (Pedigo, 1991).  
It is usually expressed as number of insects per unit area.

It is some times expressed as insect equivalents. It is the amount of injury that could be produced by one pest through it complete life cycle.

There are number of methods for the determination of EIL

### 1. Norton's model

$$Q = C / PDK$$

Where Q = Level of pest attack

P = Price of the produce per ton

C = Cost per hectare of applying insecticide

D = Loss in yield

K = Reduction in pest attack

### 2. Pedigo model

$$EIL = C / VID$$

Where

C = Cost of management per hectare

V = Market value of the commodity (Rs/kg)

I = Injury units per insect

D = Damage per unit injury

In case, some loss of the insect is avoided then

$$EIL = C / VIDK$$

Where K = Proportionate reduction in damage

$$EIL = \text{Gain threshold} / \text{Damage per insect in kg} \times \text{Amount of loss avoided} \\ = \text{Insects / ha}$$

- **Economic Threshold (ET) :** This was developed by F. DuToit. It takes into account the possible changes in pest population

$$ET = EIL \times c^{-x}$$

Where C = Factor of increase per unit time

x = Time period

- **Economic Threshold Level (ETL):** The density at which the control measures should be applied to prevent increasing pest population from reaching the economic injury level is called economic threshold level. ETL always represent a pest density lower than that of EIL to allow the initial of control measures before the pest density reaches the EIL.

$$ETL = EIL - \text{Daily reproduction rate of insect}$$



## 9.7 DETERMINATION OF ECONOMIC THRESHOLD LEVEL

Economic threshold level may be determined experimentally as given below:

- Measure yield and quality of the crop for a range of pest densities, including zero pests by means of controlled experiments
- For each management practice to be analyzed, measure yields and total crop revenues
- Compute total crop revenue for each management action at each pest density by multiplying yield by price per unit of output
- Subtract cost of each management action from crop revenue for that action at each of the initial pest densities to obtain net revenues
- Beginning at very high pest densities and moving to lower densities, compare net revenues of taking management action with taking no action. The pest density where the net revenues under controlled and uncontrolled conditions are equal is the economic threshold level

## 9.8 SYSTEMS APPROACH, ANALYSIS AND AGRO - ECOSYSTEM

### ■ System

It is well delineated part of the real world. It has limited part and has interrelated components. (Ex: Field, farm, village, etc.). The components of a system interact in such a way that changes in any component has repercussions for the whole system.

A system is an assemblage of objects under regular interactions. In a system “everything affects everything” and are interlinked reciprocally. A change in one object or variable will have its effect on another and will trigger a chain of events in the assemblage.

A complex system is one which has 20 or more variables.

### ➤ Desirable characters of a system

The system should provide information that is consistent, accurate, timely, economically feasible and relevant.

Other characters of a good system are

- It establishes standards

- Specifies each areas responsibility
- Delineates actions and decisions
- Easily understandable
- Identifies the decision points

The 4 main systems are patho-system, cropping system, farming system, and agro ecosystem.

➤ **Agro ecosystem**

Although agro ecosystems may be greatly simplified compared to natural ecosystems, they can still foster a rich array of population and community processes such as herbivory, predation, parasitization, competition, and mutualism. Crop plants may compete among themselves or with weeds for sunlight, soil nutrients, or water. Agro ecosystem varies widely in stability, complexity and the area they occupy.

Factors affecting the degree of stability of an agro ecosystem are kind of crops, agronomic practices, changes in land use patterns, total complexity and self sufficiency and weather

➤ **System approach**

It involves the study of the multiple factors, multiple pests and management strategies. System approach emphasizes that overall system behaving is influenced by changes in any system component.

➤ **System approach / analysis in pest management**

Complex system involving many components such as crops, pests, natural enemies and non target organism subjected to man's production oriented interventions and effect of variable weather. It can be partitioned into pest subsystem, crop subsystem and management.

➤ **Steps in system analysis**

- Define system and its boundaries
- Define key variables in the system
- Quantification of relationship
- Verification
- Validation
- Sensitivity analysis

System analysis is the application of both qualitative and quantitative techniques that enhance our understanding of the interactions between components of the crop pest system and their relationship with pest management practices.

➤ **Operation of pest management systems**

Pest management is a combination of process that includes decision making, taking action against the pest and obtaining the information used in reaching these decisions.

➤ **Sequence in system analysis**

- First step is to outline the objective of the study or project as mathematically as possible for minimizing losses and maximizing profit
- To divide the universe into two parts the part to be modeled is called the system and the remainder comprises the environment
- To develop a model of the system. The work relating to the system approach to insect pest management would fall here
- To apply control, design or synthesis to the problem in an attempt to achieve the desired behaviour

➤ **Modeling in IPM**

The term pest model can strictly be applied to any representation of one or several processes associated with pest development and control. A pest model is considered to be a mathematically or at least computer based representation of a pest population, its development and mortality processes. A model may also include a pest's relationship with the crop or livestock host and the process involved in its control.

➤ **Usefulness of models**

1. Models represent explicit hypothesis of how key components and process affect pest population development, crop damage or the effectiveness of control.
2. When hypothesis involve interaction of a number of variable which is usually the situation encountered in real world systems
3. Where independent data are available a hypothesis as a model can be tested, leading to modification of the model and identification of further key information needs.
4. Understanding the underlying processes of pest population dynamics, crop pest interaction, and effective strategies of control
5. Prediction of pest attack and extrapolation from one situation to another
6. Operational tools for real time guidance to pest control decision making

➤ **The types of models that can be used are**

- Statistical models

- Mechanistic models
- Optimization models

## 9.9 CONSTRAINTS AND STRATEGIES OF IPM IMPLEMENTATION

### I. Constraints in IPM implementation

- |                              |                              |
|------------------------------|------------------------------|
| 1. Institutional constraints | 2. Informational constraints |
| 3. Sociological constraints  | 4. Technological constraints |
| 5. Political constraints     |                              |

1. **Institutional constraints** : IPM requires an interdisciplinary, multifunctional approach for solving pest problems. Lack of coordination among disciplines, among disciplines, among research, extension and implementation and among institutes hampers the promotion of IPM.
2. **Informational constraints** : Lack of IPM information which could be used by farmers and by extension workers is a major constraint in implementation.
3. **Sociological constraints** : Convincing the farmers about the benefits of IPM is a major constraint. The farmers often consider IPM practices to be risky as compared to the use of chemical pesticides.
4. **Technological constraints** : Although IPM technologies have been developed for almost all crops; these have been validated for a few crops only. The technology needs large scale popularization for adoption at newer locations through out the country.
5. **Political constraints** : The continuance of pesticide subsidy by the government for political reasons and its tie up with the credit for crop production, acts as a major constraint to farmers' acceptance of IPM

### ➤ Strategies for IPM implementation

1. Farmers' participation
2. Government support
3. Legislative measures
4. Improved institutional infrastructure
5. Support of pesticide industry

1. **Farmers' participation** : The sustainable IPM approach requires farmers participation at every step of implementation in order to draw on his understanding of the local conditions and constraints, his innovativeness and his skills at making the best possible use of limited resources.
2. **Government support** : National policy to promote IPM requires close regulation at all stages related to the importation or manufacture, distribution, use and disposal of pesticides. Pesticide subsidies need to be eliminated in order to make IPM an attractive alternative. There is an urgent need to provide appropriate policy support for production, promotion and marketing of quality biopesticides in the country.
3. **Legislative measures** : The pesticide manufactures and farmers pass on the environment and ecological costs of pesticides to the society as a whole. Some of the farmers impair the success of IPM programme by failing to adopt a necessary practice this causing damage to adjacent areas. Such situations require suitable legislative measures.
4. **Improved institutional infrastructure** : IPM can not be implemented unless there is a basic infrastructure for plant protection in the country. There is a need to develop and support national programme capabilities for on farm testing and technology extrapolation. The training opportunities for researches, master trainers, extension workers, pesticide dealers, policy makers and farmers must be enhanced.
5. **Support of pesticide industry** : The support of pesticide industry is critical to the success of IPM programme because many farmers purchase pesticides on credit and depend on pesticide dealers for information about the pest control methods. Pesticides industry should develop target specific ecologically safe molecules, which are compatible with IPM components.

## 9.10 IMPACT OF CLIMATE CHANGE ON INSECT PESTS

The most general definition of *climate change* is, a change in the statistical properties of the climate system when considered over long periods of time, regardless of cause. According to Intergovernmental Panel on Climate Change (IPCC), it is defined as "Change in climate over time, either due to natural variability or as a result of human activity".

The global mean surface temperature is predicted to increase by 1.4 to 5.8°C from 1990 to 2100. The atmospheric concentration of CO<sub>2</sub> in 2005 was 379 ppm<sup>3</sup> compared to the preindustrial levels of 280 ppm<sup>3</sup>. The CO<sub>2</sub> levels have increased to 380 ppm<sup>3</sup> now and it is projected to reach 560 ppm<sup>3</sup> by the end of the century.

Climate change is expected to hit developing countries the hardest. Its effects are higher temperatures, changes in precipitation patterns, rising sea levels, and more frequent weather-related disasters—pose risks for agriculture, food, and water supplies. Agriculture is extremely vulnerable to climate change. High temperature eventually reduces yields of desirable crops while encouraging weeds and pests proliferation. Changes in rainfall patterns increase the likelihood of short run crop failures and long run production declines. The overall impact of climate change on agriculture is expected to be negative, threatening the global food security.

- **In the long run, the climatic change could affect agriculture in several ways**
  - Productivity, in terms of quantity and quality of crops
  - Agricultural practices, through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers
  - Environmental effects, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity
  - Rural space, through the loss and gain of cultivated lands, land speculation, land renunciation, and hydraulic amenities.
  - Adaptation, organisms may become more or less competitive, as well as humans may develop urgency to develop more competitive organisms, such as flood resistant or salt resistant varieties of rice.

Climate change can be positive, negative or neutral impact on individual pest systems because of the specific nature of interactions of host, the pest and the environment. Global climate changes affect species distribution, life histories, community composition and ecosystem function. In ecosystem, the tritrophic interaction between plants, herbivores insects and natural enemies (predators, parasitoids and pathogens) result from a long co-evolution process and effects are likely to be more pronounced at higher trophic levels.

- **Components of changing climate and their effect on host plants and insects**

| Variable                  | Mode of action                                                                | Effect<br>+/- | Impact                                                         |
|---------------------------|-------------------------------------------------------------------------------|---------------|----------------------------------------------------------------|
| Increased CO <sub>2</sub> | Increased C : N ratio<br>resulting increased plant<br>size and canopy density | –             | Increase feeding of<br>herbivore to derive more<br>amino acids |
|                           | More carbon storage in<br>roots                                               | +             | Diminished losses from<br>soil borne pests                     |

|                      |                                                                           |     |                                                                                                                                                                                                        |
|----------------------|---------------------------------------------------------------------------|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Enhanced temperature | Increase in food quality due to increase in nitrogen under stress         | –   | Sudden resurgence of insect pests                                                                                                                                                                      |
|                      | Influence the distribution of pests                                       | –   | Increase in 1° C temperature would enable species to spread 200 km northward or 140 km upwards in altitude                                                                                             |
|                      |                                                                           | +/- | Species richness of insects tends to increase with temperature, thus more species will be gained than lost                                                                                             |
|                      |                                                                           | +/- | Unfavourable areas become suitable, thereby, undoing migration; over winter at higher altitude causing pole ward extension; activity of certain pests such as cabbage butterfly may decline in plains. |
|                      | Onset of hibernation may be delayed                                       | –   | Increase period of pest activity resulting in more damage                                                                                                                                              |
|                      | Faster development rate (Multivoltine spp from Aphididae and Lepidoptera) | –   | Additional generation within a year                                                                                                                                                                    |
|                      | Predators of aphids on rabi crops may become more active                  | +   | May check aphid population                                                                                                                                                                             |
|                      | Natural enemies may enter new areas                                       | +   | Aiding in biological control of pests                                                                                                                                                                  |
|                      | The tritrophic interaction between plants, herbivores                     | –   | Disruption of biological control process, lethal                                                                                                                                                       |

|  |                                                                                                                          |   |                                                                                                                                           |
|--|--------------------------------------------------------------------------------------------------------------------------|---|-------------------------------------------------------------------------------------------------------------------------------------------|
|  | insects and parasitoids results from a long co evolution process are more likely to be effected at higher trophic levels |   | and sub - lethal damage to parasitoids                                                                                                    |
|  |                                                                                                                          | – | The endo - symbiotic bacteria associated with either parasitoids or their hosts can be suppressed by a short exposure to high temperature |

### Potential impact of climate change on Agro - ecosystem

- Increased atmospheric carbon associated with global warming could stimulate plant growth increasing the amount of feed available, although this effect may be offset by drought stress. More carbon could reduce the nutritive value of plants, causing some insect species to decline but others to multiply as they step up their feeding behavior.
- Host exposure to a greater number of pest lifecycles per growing season due to high ambient temperature could trigger deactivation of crop host resistance genes. Some cultivars could prove more vulnerable to pests as a result of stress caused by higher temperature or other climate changes.
- Pests vulnerable to high temperatures may decline in numbers or move to higher latitudes or altitudes. There could be population explosion in species that respond to higher rainfall or drought by increasing their feeding and/ or breeding behavior. New biotypes and species could evolve.
- Some natural control mechanisms could “decouple” insect pests and their natural enemies as the population of pests and predators react differently to changes in rainfall and temperature.
- Reduced effectiveness of pesticides such as CO<sub>2</sub> induced stimulation of weed root biomass which reduce herbicide efficacy.
- Changes in the population of insect vectors of plant viral diseases may alter disease incidence.

### Potential response of insects to climate change

Climate and weather can substantially influence the development and distribution of insects. Current estimates of changes in climate indicate an increase in global



mean annual temperatures of 1°C by 2025 and 3°C by the end of the next century. Such increases in temperature have a number of implications for temperature-dependent insects. Changes in climate may result changes in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in inter-specific interactions and increased risk of invasion by migrant pests. Because of the short life cycles of insects, mobility, reproductive potential, and physiological sensitivity to temperature, even modest climate change will have rapid impacts on the distribution and abundance of many kinds of insects.

Forecasted increases in atmospheric CO<sub>2</sub> and global mean temperature are likely to influence insect – plant interactions. Plant traits important to insect herbivores, such as nitrogen content, may be directly affected by elevated CO<sub>2</sub> and temperature, while insect herbivores are likely to be directly affected only by temperature.

The growth rate and development of many insect species are influenced by the temperature and moisture. As the temperature increase the lifecycles becomes faster and fecundity too. It has been observed that many species becomes more active and migrate extending their seasonal distribution or reproduce faster reducing the time taken to complete a life cycle.

The rainfall is bound to be affected by the changes in temperature will affect soil moisture, which is important for many soil dwelling herbivorous insects. These changes will be pronounced in the lower latitudes and altitudes and the insect species richness and their distribution will be influenced by these changes especially towards the larval changes/immature stages that inhabit soil and organic litter at the surface level.

Global warming accelerates insect development rate and facilitate range expansions of pests, moreover, climate change tends to increase the vulnerability of plants to herbivores. One alarming scenario is that climate warming may increase insect outbreaks.

The lesser availability of moisture coupled with excessive temperature on the lower latitudinal margins, especially in the tropical regions affect the distribution of insects especially in the larval stages of herbivorous insects. This will happen with many of the endoterygote insects like Coleoptera, Lepidoptera, Diptera and Hymenoptera, especially in the case of herbivorous insects, which are the major pests of agricultural crops. These changes not only limit the species richness in terms of distribution but also in terms of populations in terms of abundance.

With changes in climate occurring, in particular in terms of moisture and temperature, it is presumed that many herbivorous insect pest species will extend their range especially in their larval stages and may migrate northwards in terms of latitude. It is anticipated that global warming will make herbivores to shift their ranges

to higher altitudes and latitudes.

Global climate change impact on plant - pest populations depends on the combined effects of climate (temperature, precipitation, humidity) and other components like soil moisture, atmospheric CO<sub>2</sub> and atmospheric ozone (O<sub>3</sub>). A major effect of climate warming in the temperate zone could be a change in winter survival of insect pests, in northern latitudes there will be shifts in phenology in terms of growth and reproduction. Climate warming disturbs the synchrony between temperature and photoperiod; because insect and host plant species show individualistic responses to temperature, CO<sub>2</sub> and photoperiod, it is expected that climate change will affect the temporal and spatial association between species interacting at different trophic levels.

#### **Impact of climate change on population dynamics of insect pests**

- The occurrence of climate changes is evident from increase in global average temperature, changes in the rainfall pattern and extreme climatic events. These seasonal and long term changes would affect the fauna, flora and population dynamics of insect pests.
- Changes in climate and weather could profoundly affect the population dynamics of insects and status of insect pests of crops. These may arise not only as a result of direct effects on distribution and abundance of pest populations but also indirect effects on the pests' host plants, competitors and natural enemies.
- Warmer temperatures associated with climate changes will tend to influence (and frequently amplify) insect species' population dynamics directly through effects on survival, generation time, fecundity and dispersal.
- Individual insect species' responses to climate change, however, will depend on their geographic range, trophic level and natural history.
- Insect populations in mid- to high latitudes are expected to benefit most from climate change through more rapid development and increased survival. Much less is known about the effects of increased warming on tropical insect species.
- Insect species' mortality may decrease with warmer winter temperatures, thereby leading to pole ward range expansions.
- The physiological effects of climatic warming on insect species can also act indirectly through trophic interactions (i.e. host plants and natural enemies).
- Because insect species in general have relatively short life cycles, high reproductive capacity and high degree of mobility, the physiological responses to warming temperatures can produce large and rapid effects on species population dynamics. Thus temperature rise plays a pivotal role in insect population dynamics.

- Some pests which are already present but only occur in small areas, or at low densities may be able to exploit the changing conditions by spreading more widely and reaching damaging population densities.
- The abiotic parameters are known to have direct impact on insect population dynamics through modulation of developmental rates, survival, fecundity, voltinism and dispersal.
- Among the climatic factors, temperature is an important factor. Increase in temperature might affect any stage of the life cycle and therefore limit distribution and abundance through its effect on survival, reproduction, diapauses, winter mortality and flight and dispersal. In case of aphids a 2°C temperature increase causes one to five additional life cycles per season.
- The alteration in the voltinism also could be the results of warming and it is more profit to multivoltine species and voltinism could be reflected in changes in the geographical distribution.
- Elevated CO<sub>2</sub> also showed some impact on pest's population abundance, the crop grown under the elevated CO<sub>2</sub> could alter the nutritional value of plants; it may alter the insect abundance and increase the consumption rate of herbivores. Therefore, climate change would result in changes in the population dynamics of insect pests.
- Drought and precipitation play vital role in soil insect's abundance. Enhanced summer rainfall and drought conditions on soil promote rapid increase in the populations of wireworms in the upper soil. Changes in rainfall pattern affect the migratory patterns of the desert locust. The response of root herbivores to an increased incidence of summer drought is likely to vary, depending on their feeding strategy and life history.
- Shifts in climate can differentially affect the development rates of pest and predator species. In addition temperature can affect predator search. This way it affects the insect population dynamics indirectly. Global warming may cause temporal synchrony between interacting populations. Although, natural selection will tend to increase synchrony between hosts and parasitoids, asynchrony may occur if host and parasitoid respond differentially to changes in weather patterns.

#### **Impact of extreme climate/weather on pests**

- During 2008, occurrence of *Spodoptera litura* epidemic on soybean in Vidarbha region of Maharashtra and brown plant hopper in Haryana/western Uttar Pradesh belt of Basmati rice were mainly due to favourable prevailing weather conditions.
- During 2006, mealybug, *Phenacoccus solenopsis* which was never reported as a serious pest of cotton in India gained pest status on *Bt* cotton in Gujarat and during 2007 in Punjab, Rajasthan and Maharashtra causing heavy reductions in yield.

- Invasion of sugarcane wooly aphid, *Ceratovacuna lanigera* in Maharashtra in 2002.
- *Helicoverpa armigera* was a major pest of chickpea and pigeon pea, but after the introduction of *Bt* cotton in 2002, its infestation in these crops has significantly declined in the cotton based cropping system. There is no significant movement of this pest from cotton- to -pigeon pea- to- chickpea.
- Declined survival rate of brown plant hopper *Nilaparvatha lugens* (Stal) and rice leaf folder, *Cnaphalocrocis medinalis* (Guen) at higher temperature indicates the impacts of rising temperature could do the changes in the pest population dynamics of rice ecosystem.

Better understanding of the effects of climate change on insect pests will enable us to take the necessary measures to counteract or mitigate the possible negative consequences on the agricultural ecosystems. Thus, predicting the impact of climate change on insects is a very complex exercise and involves a great deal of modeling. A deeper understanding of the complex relationships between a changing climate, agriculture and agricultural pests is vital to enable those in crop health protection and management to expect and prepare for changes in pest behaviors, outbreaks and invasions. Pest management strategies in agriculture will require adjustments. Under the emerging scenario, modeling techniques, monitoring, mapping and conservation of biodiversity are likely to become the important tools of Integrated Pest Management (IPM).

## 9.11 Changing Insect Pest Scenario in the Rice Ecosystem

Insect pests cause about 10-15% yield losses in rice. The average yield losses in rice have been estimated to vary between 21-51 per cent. Yellow stem borer, brown plant hopper and gall midge are the key pests in rice causing 25-30%, 10-70% and 15-60% yield losses, respectively. At national level, stem borers accounted for 30% of the losses while plant hoppers (20%), gall midge (15%), leaf folder (10%) and other pests 25 per cent.

Depending upon the crop age, the incidence of insect pests and resultant yield losses vary. During the first 30 days after transplanting significant yield losses are reported due to stem borer and gall midge. During 30-60 days after transplanting was most vulnerable resulting in major yield losses (20- 68%) mainly due to stem borer, gall midge, leaf folder and brown plant hopper. After 60 days after transplanting, the crop damage is inflicted by stem borer and leaf folder causing 10 to 48% damage.

With the introduction of changes in types of varieties being cultivated, practicing of different cultivation systems and associated alterations in rice based cropping systems, certain pests earlier regarded as minor pests have now assumed significance as pests of regional significance.

Among various rice based cropping systems, rice-wheat cropping system is the major system followed by rice-rice and rice fallow. In this context, there is a change in resource utilization pattern and also pest dynamics within diverse ecologies or cropping systems. Among the cropping systems, the insect pest problems are relatively more in rice-rice-rice or rice-pulse than rice-maize or rice –wheat cropping systems. Among the different ecologies, irrigated ecology harbours most number of insect pests.

### Current pest scenario of rice

Before green revolution, stem borer, gall midge, rice hispa, whorl maggot, cut worm and thrips were considered as major pests of rice. The major insect pests of National significance today are, rice yellow stem borer (YSB) *Scirpophaga incertulas* (Walker), brown plant hopper (BPH), *Nilaparvata lugens* (Stal), whitebacked plant hopper (WBPH), *Sogatella furcifera* (Horvath), leaf folder *Cnaphalocrocis medinalis* (Linnaeus), gall midge (GM) *Orseolia oryzae* (Wood-Mason), green leafhopper (GLH) *Nephotettix virescens* (Distant) and gundhi bug *Leptocorisa* spp., whorl maggot, *Hydrellia* spp., rice hispa,

*Dicladispa armigera*, climbing cutworm, *Mythimna separata* Walker, swarming caterpillar, *Spodoptera mauritia* Boisduval, panicle mite, *Steneotarsonemus spinki* and thrips, *Stenchaetothrips biformis* have regional significance.

### Stem borers

There are five different stem borer species distributed throughout India. These are Yellow stem borer (YSB), *Scirpophaga incertulas* (Walker), Pink Stem borer (PSB), *Sesamia inferens* (Walker), White stem borer (WSB), *Scirpophaga innotata* (Walker), Dark headed borer (DHB), *Chilo polychrysus* (Meyrick) and Striped stem borer (SSB), *Chilo suppressalis* (Meyrick).

Since the introduction of double cropping in rice particularly in irrigated ecologies of Southern India, yellow stem borer remains the predominant, widespread and destructive stem borer species in India. Deep water rice are more affected by yellow stem borer. Consequent to the extension of rice cultivation to non-traditional belts like north western parts and hill regions of India, particularly under rice-wheat system, other stem borer species pink stem borer and white stem borer

have become important. Pink stem borer is dominant in North Western India particularly during reproductive phase while, white stem borer has become predominant in Kerala and hills of Northern region. Dark headed borer (6-20%) is reported from Tamil Nadu. Zero tillage (ZT) was found to harbour more larvae of yellow stem borer in the rice stubbles as compared to conventional tillage.

The stem borers are called 'K' strategist pests and population growth assumes a typical 'S' curve. The reasons for stem borer still remaining a dominant pest even today is due to lack of highly resistant varieties against YSB in the primary gene pool and being an internal borer YSB larvae remains protected from spray deposits.

The stem borer still remains the most important pest in rice in the country. However, the incidence of stem borer has decreased in the recent years in Punjab, due to change in planting time. In Punjab, the planting time has been preponed to the month of May in 1990s based on available water and electricity. But this led to severe incidence of yellow stem borer. Realizing this fact the Government has taken a decision that rice plantings should not be taken up before June. This has resulted in reduction in stem borer populations due to non-availability of food/survival source to stem borers. Altering the time of planting based on peak stem borer occurring periods in their region aided in reduction of stem borer populations.

### Plant hoppers

Rice plant hoppers are major pests across the country especially in irrigated rice. Two species viz., brown plant hopper and white backed plant hopper are of economic importance. Besides direct damage to crop by nymphs and adults sucking phloem sap and leading to hopper burn, BPH also transmits viral disease like rice grassy stunt. In ecological terms BPH are typical 'r' strategists and show 'j' type of growth curve. Plant hoppers generally appear in field about one month after transplanting. However, in late planted crops they may appear on young crop.

Brown plant hopper, a pest of minor importance till mid-sixties, assumed most destructive pest status in 1970s and first serious epidemic of BPH occurred in 1973. Series of BPH outbreaks since then were recorded in Karnataka (1975 and 1985), in Krishna and Godavari deltas of A.P (1976-1983) and Telangana (1980), Madhya Pradesh and Orissa (1976), Tamil Nadu (1977 and 1982).

After the introduction of BPH resistant varieties like Vajram, Chaitanya and Krishnaveni in Krishna and Godavari deltas since 1983 there was a decline of BPH populations. Another plant hopper i.e. white backed plant hopper up surged in early nineties. Deploying resistant varieties with single gene conferring high level of resistance has led to development of virulent biotypes. Once thought to be a

seasonal pest, of late plant hoppers occur throughout the year in serious proportions.

Closer spacing, use of high dose of nitrogenous fertilizers, use of broad spectrum or ineffective insecticides early in the season etc., favour rapid buildup of BPH populations. Studies have also shown that rainfall profoundly influences BPH build up by creating favourable high humidity at the crop base.

Outbreaks of plant hoppers have caused serious concern and in the last decade plant hoppers, have rapidly spread to newer non-traditional areas of Punjab, Haryana, parts of U.P. During the last decade status of white-backed plant hopper as a pest has tremendously increased both in low land and upland areas particularly where rice varieties resistant to BPH are grown.

In Andhra Pradesh, despite of availability of BPH resistant varieties, farmers extensively cultivate susceptible varieties like BPT 5204, HMT Sona etc., for better market price leading to increased reports of plant hopper incidence. In Coastal areas of Andhra Pradesh resistance to neonicotinoids is reported due to extensive and prolonged use of these chemicals for several years. Further, use of synthetic pyrethroids or resurgence causing chemicals early in the season aggravates the plant hopper problem.

### **Leaf folder**

Leaf folders have attained major pest status with the introduction of high yielding varieties and particularly in areas of high fertilizer use. Four species of leaf folder occur viz., *Cnaphalocrocis medinalis* (Guenee), *Marasmia patnalis* (Bradl), *M. exigua* (Butl) and *Brachmia arotraea* (Meyr). Among these *C. medinalis* is the dominant and widespread species. Leaf folder damage can be observed at any stage of the crop growth but generally conspicuous during active tillering to booting stage.

First outbreak of leaf folder occurred during 1985 in Haryana resulting in extensive damage. Later leaf folder has spread to all rice growing areas. Leaf folder outbreak was observed in the Cauvery delta region in Tamil Nadu during 2006 and damage was moderate to severe throughout Punjab during 2007. In the recent years, the leaf folder has become wide spread and increased intensities are noticed in many states of the country.

### **Gall midge**

Rice gall midge is a dipteran belonging to family Cecidomyiidae and a key pest of irrigated and rainfed shallow land rice. The Asian rice gall midge, *Orseolia oryae* (Wood-Mason) is common in India. In some regions like Telangana and North Coastal Andhra Pradesh, Kuttanad in Kerala, Vidharbha in Maharashtra, Sambalpur



in Orissa, Coastal Karnataka are endemic to this pest, where moderate to severe yield losses are reported.

Gall midge now has six biotypes and now spreading to new areas of Bihar and Manipur. Occasionally, this pest has been reported in upland and deep water rice. It occurs only during certain years, based on weather and crop varieties in localized pockets of Punjab, Himachal Pradesh, Haryana, Uttarakhand, Western U.P, and Jammu Kashmir etc.

Early onset of monsoon followed by dry spell, leading to delayed transplanting often results in severe damage in endemic areas. Gall midge is usually a pest of wet season. It assumed serious pest status in sixties and early seventies in Orissa, Bihar, Andhra Pradesh, Kerala and Karnataka. Since 1987, it also started damaging dry crop. East and West Godavari districts of Andhra Pradesh experienced severe incidence of gall midge during rabi, 1987. Following large scale cultivation of gall midge resistant varieties in mid seventies its incidence decreased.

Development of a new biotype (biotype 4) in North Coastal A.P in 1986 marks a significant change causing yield loss worth \$120 million. This was followed by development of location specific resistant varieties for gall midge and the incidence of gall midge appears low, except in few localized patches.

### **Green leafhopper**

Two species, *Nephotettix virescens* (Distant) and *N. nigropictus* (Stal.) are most common. While direct damage seldom causes economic loss, viral disease (rice tungro) transmitted by both the species results in economic loss. RTV confined to eastern states till 1981, caused extensive damage in coastal Tamil Nadu and A.P in 1983 and 1984 and East and West Godavari districts of A.P during kharif 1990. Green leafhoppers are maintaining their importance as their incidence is reported from many places in the country.

### **Gundhi bugs**

Three species of ear head bugs viz., *Leptocorisa oratorius*, *L. acuta* and *L. pesudolepida* are reported and among these *L. oratorius* is common in South, West and Eastern regions, while *L.acuta* is dominant in North. Gundhi bug has become a major problem in North Eastern states, especially, Manipur since early 2000s. Though considered a minor pest in Southern India, assumed serious proportions in some parts of A.P (North Telangana and North Coastal A.P) during 1990s causing up to 100% yield loss. Rice ear head bug appeared in severe proportions in Maharashtra and in some pockets of South Gujarat during 2007.



**Rice hispa**

Rice hispa, *Dicladispa armigera* is occasionally a major pest in rice particularly in coastal areas of Assam, West Bengal, Andhra Pradesh and Tamil Nadu. It is now a major pest of rice particularly in North Eastern, Eastern and Central regions of India. In recent years incidence of rice hispa is on increase, particularly in the wet season.

Rice hispa has caused yield losses in Andhra Pradesh, Bihar and West Bengal during 1970s - 80s. There has been a decline in its incidence in Andhra Pradesh since 1985, except sporadic incidences. Of late hispa population was found to be severe in Himachal Pradesh with yield loss of 34.3% (during 2007). Rice hispa is emerging as a major pest in Himachal Pradesh and Assam.

**Defoliators**

The cutworms, *Mythimna separata* are becoming serious in many rice growing areas in the eastern parts of the country. Occasionally, *Spodoptera mauritia* is assuming serious proportions. Sporadic out breaks of *Mythimna* have been recorded in Madhya Pradesh, Orissa, Uttar Pradesh and Andhra Pradesh during 1975-1980 causing yield loss upto 13-30%. Since mid eighties, ear cutting caterpillar started appearing in a severe form along with BPH in coastal districts of Andhra Pradesh.

Recently, severe damage was reported in Assam it has been regularly occurring in Coastal A.P and Eastern states. Immediately after floods infestation of swarming caterpillar is reported in many areas. There was an outbreak of *Mythimna separata* in Pattukottai in Tamil Nadu during kharif 2007. Outbreak of swarming caterpillar was reported in Nuapara district of Orissa in kharif 2006 and some pockets of Orissa during kharif 2007 mainly due to early rain followed by a dry spell for a period of 15 to 20 days.

Severe outbreak of swarming caterpillar was reported from Maharashtra (2001) and West Bengal and Orissa during 2005. Outbreak was reported from Nuapara district of Orissa during 2007, with population levels as high as 10-22 larvae/sq.m. The incidence of rice ear cutting caterpillar was observed in about 33% of the high yielding varieties and incidence was as high as 45 to 65% in some areas of Pusa, Bihar during 2007. Though sporadic in occurrence, heavy losses occur during outbreaks. In last few years these pests have been reported in serious proportions in rainfed rice areas of Bihar, Uttar Pradesh, Orissa and Madhya Pradesh.

**Case worm**

The most common species is *Nymphula depunctalis* (W). Under poor drainage rice crop may suffer from case worm damage. It is commonly found in low land and flooded rice fields, particularly in parts of Assam, Orissa, Bihar and West Bengal. Severe outbreak of case worm occurred as post flood pest in Assam causing 20 to 90% damage to the crop during 2007. Moderate to heavy attack of case worm particularly in Patna and Nalanda district of Bihar was also reported during 2007.

**Other pests**

Termites occur as pests in light soils and under situations of marginal rainfall and drought. In these areas termites severely affect aerobic rice cultivation. Mealy bug, become an important pest of upland rice in West Bengal.

Recently, black bugs, *Scotinophora lurida* and *S. coarctata* were noticed in severe form especially in hybrids in Tamil Nadu. It has emerged as a common pest during vegetative stage of rice crop in rainfed and irrigated wet land environments particularly in poorly drained fields. Damages occur in dry season rice crops and densely planted fields are preferred. It is also appearing as an important pest in Gujarat.

During the years 1999-2003 for about four years, due to occurrence of prolonged dry spells and rise in temperatures the incidence of leaf mite (*Oligonychus oryzae*) and panicle mite (*Steneotarsonemus spinki*) were reported from Andhra Pradesh.

Rice thrips (*Stenochaetothrips biformis*) has become important in rainfed rice during the seedling stage or within a fortnight after sowing or in early transplanted crop. White grub (*Holotrichia* spp.) has emerged as a major pest in hilly regions of Uttaranchal state. Root aphid (*Tetraneura nigriabdominalis*) has emerged as a pest of significance in upland rice.

In Kerala, blue beetle (*Leptispa pygmoea*), has recently emerged as an important defoliator, as most of the rice varieties cultivated in this area found to be susceptible to the pest. The incidence of beetle is more during the first crop season (July-August) favoured by low temperature and high relative humidity.

Similarly, insect pest complex of rice in Northeastern region is changing and flea beetle, *C. basalis*, which was earlier noticed to damage seedlings has now established as pest of regular occurrence in early vegetative stage.

**Changing insect pest scenario**

Stem borer incidence was low up to 1970s, moderate till 1975 and severe and widespread from 1980 onwards and still remains as a major rice pest. BPH not considered as a pest till 1970s assumed major pest status from 1990s to till date. Moderate incidence due to WBPH is reported since 2000 and potential pest to assume serious proportions in the coming decade, particularly in irrigated ecologies. Leaf folder moderate till eighties, has become a serious pest in the recent decades. Gall midge is maintaining its status and through evolution of new biotypes may pose major problems in future. Armyworm, hispa, caseworm and whorl maggot incidences increased since 2000 in localized areas. Green leafhopper and grasshoppers at low from 1985- 2000 are increasing in proportions in the recent years. The number of rice pests has increased from 3 to 15 since 1965 to 2009, apart from some more pests of regional significance.

Yellow stem borer, leaf folder and BPH in West Bengal, termites and mealy bugs in Bihar, rice hispa in Uttar Pradesh, BPH and WBPH in Haryana, pink stem borer and leaf folder in Punjab, YSB, BPH, rice hispa and root grub in Orissa, leaf folder and GLH in Madhya Pradesh, gundhi bug in Maharashtra, army worm and leaf folder in Gujarat, leaf folder, whorl maggot and panicle mite in Andhra Pradesh, gundhi bug and gall midge in Karnataka and leaf folder, leaf mite, rice black bug and armyworm in Tamil Nadu have become important because of their changing status during 2006-2009.

**Possible reasons for the shifts in insect pests**

- Growing varieties lacking resistance to major pests: In many states despite of availability of resistant/tolerant varieties, farmers still cultivate susceptible varieties mainly for better market price and fine grain quality. Particularly in Andhra Pradesh, BPT 5204 is the most extensively cultivated variety despite being susceptible to many insect pests.
- Extensive cultivation of high yielding varieties: High yielding varieties responsive to higher doses of fertilizers are being cultivated by farmers, where insect pest problems have accentuated.
- Intensified rice cultivation throughout the year providing constant niches for pest multiplication
- Imbalanced use of fertilizers, particularly application of high levels of nitrogen has led to increase of leaf folder and plant hopper incidence
- Altered weather or climatic conditions: Changes in temperatures or rainfall patterns will have profound influence on pest scenario. Leaf mite and panicle mite which

were not considered even as minor pests in rice during 1980s, have now assumed major pest status mainly because of rise in temperatures and changes in climate. The winter mortality of *Nezara viridula* is predicted to be reduced by 15% with each rise of 1°C. Brown plant hopper is 17 times more tolerant than its predator *Cyrtorrhinus lividipennis* at 40°C subsequently resulting in rise in BPH populations.

- Indiscriminate use of insecticides: Due to injudicious use of some insecticides rice gall midge resurgence was observed in Krishna and Godavari districts of Andhra Pradesh during rabi 2002 and 2007-08.
- Development of resistance to insecticides: Due to development of resistance in brown plant hopper to neonicotinoids
- Planting situations: Under late planting situations, increased incidence of whorl maggot was observed
- Delay in planting season: Because of delayed onset of monsoon and delayed kharif, the crop escaped from stem borer incidence but subsequent rabi crop suffer with heavy infestation
- Shift in varietal coverage: Due to large scale cultivation of BPH resistant varieties in Godavari zone, stem borer is on the rise while, in Telangana region because of large scale cultivation of gall midge resistant, fine grain varieties incidence of BPH and panicle mite were on increase.
- Harmful cultural practices: Because of continuous cropping and application of high nitrogenous fertilizers, leaf folder problem is on the rise in Southern zone.
- Evolution of new biotypes: In the last three decades, rice gall midge has evolved in response to selection by introduction of resistant varieties in rice ecosystems across the country. Now the pest is a widespread one with emergence of six biotypes, causing serious losses in new areas like Bihar and North Eastern states of Manipur in addition to traditional areas of Orissa, A.P, Madhya Pradesh and Kerala.
- Changes in cultivation practices: After rice, there is substantial increase in the Maize area under zero tillage. During such situations the stubbles are left like that increasing the chances of stem borer survival. Further, both rice and maize are common hosts for pink stem borer and its incidence is likely to increase in rice in the coming years.

**Changing cultivation practices vis a vis insect pests****System of Rice Intensification (SRI) cultivation**

In Andhra Pradesh and Tamil Nadu, SRI method of cultivation is also being practiced by some farmers aimed at water saving, organic cultivation etc.,. Some of the major insect pests viz., gall midge, whorl maggot and brown plant hopper are less active due to change in the microclimate. Significant reduction in colonization and population buildup in BPH was observed because of wider spacing, intermittent irrigation and rotary weeder operation. Multi-location evaluation of hybrids and varieties under SRI revealed that thrips damage was more in SRI and stem borer damage was less (particularly dead heart incidence) in SRI than normal method of cultivation. Studies at TNAU revealed that the crop growing environment in SRI permits leaf folder upsurge in many occasions and green leafhopper to some extent. Leaf and panicle mite damage was also high in SRI. Root knot nematode build-up was also high which is influenced by the irrigation pattern. It is visualized that the arthropod recruitment and species diversity were less in SRI than conventional rice cultivation and the effect was more in wet season than in dry season. SRI discourages significantly the activities of aquatic arthropods.

**Organic rice:** The yields in organic rice are low or the impact of organic cultivation is realized only after 5-6 seasons of cultivation, still the price tag and premium market associated with the label “organic” is tempting some of the farmers to go in for this cultivation. This system cannot be advocated in high intensive areas of rice production except in certain pockets like traditional hilly areas. Vermicompost and green manure had low pest damage. Though organic farming was found to reduce the disease and nematode populations significantly, it is very difficult to control a pest epidemic in an organic way.

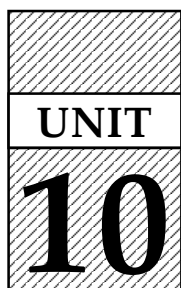
**Aerobic rice:** In traditional upland rice areas, termites, mealy bugs and root aphids and root knot nematode are common apart from the regular pests that occur in rice such as stem borer, leaf folder and gundhi bug.

**Boro rice:** In north eastern India, upland rice cultivation is common and only one crop is taken in a year. However, in Assam, wet land cultivation involves three crops in a year viz., Ahu (March- April), Sali (July-August) and Boro or winter (Dec.-Jan). The climate in this region with high rainfall and humidity is conducive for their incidence and multiplication. Hispa is an important pest of this area and it is reported that increase in temperatures had an impact on the biology of the pest.

Globally, it is understood that there is an increase in temperatures which has a significant impact on the precipitation also. These abiotic factors influence the biology and population dynamics of the pests at the micro level. The change in cultivation practices also alters the micro- environment which is the niche for many of the biotic agents.

(Source: Changing Insect Pest Scenario in the Rice Ecosystem – A National Perspective by K. Krishnaiah and N.R.G.Varma; Rice Knowledge Management Portal <http://www.rkmp.co.in>)





# Pesticide Applications Equipments

## 10.1 Types of appliances

Plant protection equipments fall under three major categories

- I. Dusting equipments                      II. Spraying equipments
- III. Other equipments

Each of these 3 categories is again broadly grouped into 2 further categories  
(i) Manually operated, and (ii) Power operated.

### I. Dusting equipments

#### Dusters

Appliances that are used for applying dry formulation of pesticides are called as dusters. They make use of an air stream to carry the chemicals in finely divided and dry form to the plants.

A duster consists of hopper which contains an agitator, an adjustable orifice or metering mechanism and a delivery tube. A rotary fan or a bellows provide the conveying air.

#### Hand operated dusters are

- 1. Rotary type                                      2. Plunger type
- 3. Bellows type                                    4. Traction dusters

#### 1. Rotary type dusters

They are also known as crank dusters and fan type dusters. They vary in design and may be shoulder, back mounted or belly mounted. It consists of a blower with gear box and a hopper with a capacity to hold 4 to 5 kg of dust. They are used for dusting field crops, vegetables crops, small trees and bushes in orchards. The efficiency is 1 to 1.5 ha per day.

#### 2. Plunger type dusters

The pump in such dusters generates air blast and passes it into the dust chamber

causing the dust blow out through the discharge outlet. It is used in kitchen gardens, cattle sheds, poultry houses etc.

### 3. Bellow type duster

In this type of dusters the air blast is produced by expansion and contraction of bellows which passes into the dust chamber and discharges out the dust. It is used in kitchen gardens.

### 4. Traction dusters

For large scale dusting the duster is mounted on wheels and the blower fan is connected to the wheels. Traction of the duster runs the fan which blows the dust out.

## II. Spraying equipments

### Sprayers

Equipments used for spraying the liquid formulation of pesticides are known as sprayers. These are used to control insects, mites, weeds and diseases. The main function of sprayer is to atomize the spray fluid into small droplets and eject it with some force safely and properly consuming least energy to hit the target with least disturbance to the environment. A sprayer consist of tank, pump, agitator, pressure gauge, valves, filters, pressure chamber, hose, spray lance, cut of device, boom and nozzle.

There are 3 types of hand operated sprayers

1. Hand operated hydraulic sprayers
2. Hand operated compression sprayers
3. Air blast sprayers

#### 1. Hand operated hydraulic sprayers are

- |                         |                       |
|-------------------------|-----------------------|
| a. Hand syringes        | b. Hand sprayers      |
| c. Bucket pump sprayers | d. Foot pump sprayers |
| e. Rocker sprayer       | f. Knapsack sprayers  |
| g. Wheelbarrow sprayers |                       |

##### a. Hand syringes

It consists of a cylinder into which the spray fluid is drawn during the suction stroke and delivered during the pressure stroke and discharge through nozzle. It is useful to operate in a small area.

##### b. Hand sprayer

It consists of a built in pump. The tank capacity is 0.5 to 1 litre. The delivery tube is directly attached to the piston which discharges the spray



fluid during the pressure stroke. It is used for spraying in kitchen gardens.

**c. Bucket pump sprayers**

It consists of a plunger, one or two barrels, a stirrup and a foot rest. It has no built in tank and mostly buckets are used as containers for holding spray fluid at the time of spraying. Two persons are needed to work with this pump. This is suitable for spraying shrubs, low crops and nurseries.

**d. Foot pump sprayer**

It is used for spraying tall crops as well as fruit trees up to 4 meters long. The piston of this sprayer is operated by the foot. The pump is fixed on an iron stand and a pedal attached to the plunger rod operates the sprayer by its upward and down ward movements. An additional container is required to hold spray fluid as there is no built in tank.

**e. Rocker sprayer**

These sprayers function like foot sprayers, but the piston is connected to a lever which can be rocked to and fro to operate the piston. It has a large detachable air chamber. An additional container is required to hold spray fluid as there is no built in tank. A high pressure should always be maintained for uniform spraying. This is used for spraying coconut and palm trees.

**f. Knapsack sprayers**

It is similar to bucket type and fits comfortably on the back of the operator. It consists of a pump, a lever to operate, a built in tank of 15 litres capacity, hose, lance and a nozzle. The pressure is developed with help of lever handle. The pump has to be operated continuously for maintenance of necessary pressure. It is suitable for hilly and muddy terrains where the use of larger sprayers or power sprayers is not possible.

**g. Wheel barrow sprayers**

A rocker or a pedal pump sprayer can be mounted on a trolley provided with a tank to make a wheel barrow sprayer. The advantage is that the operator is saved from carrying the weight of the machine and spray liquid. The disadvantage is that it is tiring to push the machine on even grounds.

**2. Hand operated compression sprayers**

**a. Pneumatic hand sprayers**

**b. Pneumatic knapsack sprayers**

**a. Pneumatic hand sprayers**

These sprayers employ air pressure to force the liquid out and therefore are kept partly empty to provide space for development of air pressure.

They comprise of a tank and air pump to develop pressure and are provided with an air check valve at one end and a delivery tube connected outside to a nozzle through a trigger control valve. It is used in glass houses and in kitchen gardens.

**b. Pneumatic knapsack sprayers**

It comprises of a tank for holding the spray fluid with compressed air, a vertical air pump with a handle, a filler hole, a spray lance with a nozzle and cut off device. Before starting the sprayer, air is compressed into the empty space in the tank. As the spray continues the pressure drops continuously. It is used in large areas for the control of public health insects like mosquitoes, house flies etc. and in poultry houses.

**3. Air blast sprayers**

**a. Hand atomizer**

It consists of a pump, nozzle, a tank and a delivery tube. A succession of up and down strokes throws the intermittent jets of the spray liquid. This appliance is suitable only for the household and kitchen gardens.

**III. Other appliances**

- |                                |                                              |
|--------------------------------|----------------------------------------------|
| a. Mist blowers                | b. Fog generators                            |
| c. Smoke generators            | d. Liquefied gas aerosols (or aerosol bombs) |
| e. Soil injecting guns         | f. Seed treatment drums                      |
| g. Flame throwers              | h. Granular applicator                       |
| i. Dust applicator for burrows | j. Bird scarer                               |

**a. Mist blowers**

This works on the same principle as spray blowers. The spray liquid is atomized first by a hydraulic pump and then blown by an air blast produced by a blower. The size of the particle is 50 to 150 microns and dilution is reduced by 20-80 per cent. It is used for controlling mosquitoes.

**b. Fog generators**

The drop let size in these machines is about 1 to 50 microns which enable to remain floating in the air longer to kill the flying insects. These are used for treating larger areas in shorter time with smaller quantities of materials. These are used for controlling mosquitoes, flies and other insects inside the building.

**c. Smoke generators**

These are simple canisters in which some amount of insecticide is mixed with

a slow burning material. The size of smoke particles are 0.001-0.1microns. These are used in confined areas like green houses, warehouses and godowns.

**d. Liquefied gas aerosols (or aerosol bombs)**

Aerosols refer to a fine spray ejected by pressurized can. These are made up of strong metal containers having a rapidly volatilizing and greatly compressed liquefied gas with 10-20 % insecticides in a non –volatile oil and fitted with a delivery tube. These are used in small enclosed spaces for killing flying insects like mosquitoes, flies etc particularly during out door camping.

**e. Soil injecting guns**

These are also called as soil fumigators. These are used for the control of soil insects and soil nematodes. It consists of a tank, a pump barrel, plunger assembly, injector nozzle, thrust handle and an injection handle. By holding with thrust handle, the equipment is thrust into the soil till the nozzle rod gets into the soil completely and the injection needle is pressed to release the calculated quantity of liquid fumigant.

**f. Seed treatment drums**

It consists of rotary drum having rows of circumferentially spaced stirring plates mounted therein. When the drum is rotated about a substantially horizontal axis the plates raise seed from the bottom of the drum. At their uppermost positions the plates are inclined so that seed falls from the plates into a vertical passage defined between adjacent rows of plates. Pesticide is introduced inside the drum such that the agent is applied to the seed traveling downwardly along the vertical passage.

**g. Flame throwers**

It is used for killing locust swarms and hairy caterpillars. It is ordinary pneumatic sprayer filled with kerosene for producing flame but the lance and nozzle are replaced with metal burner.

**h. Granular applicator**

It consists of a hopper to hold the granules, a regulating mechanism to ensure constant flow of granules to the point of distribution and a means of operating the regulating mechanism.

**i. Dust applicator for burrows**

The plunger type duster can also be used for driving dust into burrows. These are used in rodent control.

**j. Bird scarer**

It produces loud noise at regular intervals to scare away the birds. It consists of a big chamber to hold calcium carbide, a small chamber inside the former

to hold water and a combustion chamber. The explosions results from the acetylene gas generated when water comes into contact with calcium carbide in slow trickles. The frequency of sound production can be adjusted by regulating the flow of water.

## 10.2 POWER OPERATED DUSTERS AND SPRAYERS

### I. Power operated dusters

These dusters are provided with petrol driven motor which runs both the agitator inside the hopper and the blower (fan). The blower produces the air blast which carries the dust particles to the delivery tube (hose) to be expelled out through the nozzle mounted on a boom. These appliances are used for larger areas.

### II. Power operated sprayers

#### a. Hydraulic power sprayer

These machines are powered by 1-5 horse power petrol engines and are composed of pump, a tank, with an agitator, a pressure regulator valve, a pressure gauge, suction and delivery hoses having a spray gun or lance with a nozzle or several nozzles mounted on a boom. According to capacity to discharge liquids these are categorized into low pressure low volume sprayers or high pressure high volume sprayers

#### b. Spray blowers

These are suited for concentrate spraying. The spray blowers combine a low pressure low volume hydraulic sprayer and an air blower. Atomization of the spray liquid is first done by pump by forcing the liquid to pass through a series of nozzles. The droplets thus atomized are further broken down into still smaller particles by an air blast produced by a blower which also blows the particles to the target surface.

#### c. Electrodyne sprayer (Electrostatic Sprays)

The functioning of the electrodyne sprayer is based on a system which atomizes and propels charged droplets of chemical spray by electrical forces set up between a nozzle with a positive high voltage charge. Since the charged droplets are readily deposited on a plant, the total deposit on the foliage can be significantly increased compared to uncharged sprays.

The liquid pesticide is poured into a bottle and fed by gravity to the nozzle, where it picks up charged droplets (positive charges) generated by batteries. The liquid leaves the nozzle in a number of uniform ligaments which break

up into electrically-charged droplets. The positively charged droplets move along curved electrical field lines towards and around the plants, covering the visible as well as hidden surfaces. The size of the droplets ranges between 20 and 200 microns. A special feature of this type of sprayer is that the formulations used in it come in a special bottle fitted with the particular nozzle required.

**d. Controlled - droplet application (CDA) sprayers**

These sprayers apply the correct size and uniform droplets on a given target area so that optimum use is made of the spray volume and dosage. It is a logical extension of the ultra low volume (ULV) concept. The most promising method of controlling droplet size within fairly narrow limits is by using centrifugal energy nozzles (spinning discs or cups) which adjust droplet size by varying their rotational speed. A suitable formulation and flow rate are selected so that at a given rotational speed, droplet formation is from ligaments with a minimum number of satellite droplets.

The volume of spray depends not only on the droplet size selected but also on droplet density. Uniform droplet density can be obtained by using as little as 500 mL ha<sup>-1</sup> of the formulation with a droplet size of 46  $\mu$ m or 1-8 L ha<sup>-1</sup> at 70  $\mu$ m or 200 L ha<sup>-1</sup> at 340  $\mu$ m droplets. The advantages of CDA are it improves spraying efficiency, eliminate waste and protect environment.

### 10.3 TYPES OF NOZZLES AND THEIR USES

■ **Nozzles**

Nozzles are specially designed apertures to break up the liquid coming out of the spray tank into fine droplets. Nozzles are generally best suited for certain purposes and less desirable for others. In general, herbicides are most effective when applied as droplets of approximately 250 microns, fungicides are most effective at 100 to 150 microns, and insecticides at about 100 microns.

➤ **Functions of a nozzle**

Nozzles perform three main functions

1. Regulate flow
2. Atomize the mixture into droplets
3. Disperse the spray in a desirable pattern

A typical spray nozzle consists of a base, a screw cap, a disc or orifice plate, a washer, a whirl plate and with or without a strainer.

The nozzles are of different types suited to different types of work include a)

Hydraulic energy b) Gaseous energy c) Centrifugal energy d) Kinetic energy and e) Thermal energy

#### Different types of nozzles and their main uses

| S.No. | Energy      | Type                                                    | Uses                                                                                                                                        |
|-------|-------------|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1     | Hydraulic   | Impact<br>Fan<br>Even spray fan<br>Cone<br>Solid stream | Mainly used for herbicide applications<br>Spraying flat surfaces such as soil and walls<br>Band sprays<br>Foliage sprays<br>Spot treatments |
| 2     | Gaseous     | Air blast<br><br>Vortical                               | Foliage sprays, especially tree crops and bushes<br>Aerosol space sprays                                                                    |
| 3     | Centrifugal | Spinning disc<br>or cage                                | Mist / aerosols for drift and space sprays<br>and also to fit air carrier sprayers                                                          |
| 4     | Kinetic     | -                                                       | Coarse sprays, especially herbicides                                                                                                        |
| 5     | Thermal     | -                                                       | Space treatments, especially inside buildings<br>and forests                                                                                |

#### There are 3 basic spray patterns

1. Flat fan
2. Hollow cone
3. Full cone

Each of these has specific characteristics and applications

#### 1. Flat - fan nozzles

Flat - fan nozzles are widely used for broad cast spraying of herbicides and some insecticides. They produce a tapered-edge, flat-fan spray pattern.

Flat fan spray nozzle is of 3 types

##### i) Even flat fan nozzle

Even flat - fan nozzles apply a uniform coverage across the entire width of the spray pattern. They are used for banding pesticides over the row and should not be used for broadcast applications.

##### ii) Flooding fan nozzle

Flood fan nozzles produce a wide-angle, flat-spray pattern and are used for applying herbicides and mixtures of herbicides and liquid fertilizers. These

nozzles are most effective in reducing drift when they are operated within a pressure range of 10 to 25 PSI.

**iii) Turbo flood jet nozzle**

This nozzle produces larger drops and a more uniform spray pattern. The turbo flood nozzle is designed for use with soil incorporated herbicides and liquid fertilizer.

**2. Hollow cone nozzles**

Hollow cone nozzles are generally used to apply insecticides or fungicides to field crops where complete coverage of the leaf surface is important. The hollow cone pattern is used for applications where a fine spray pattern is needed for thorough coverage. Spray drift is higher with hollow cone nozzles than with other nozzles as small droplets are produced.

**3. Full cone nozzles**

Full cone nozzle produces a swirl and a counter swirl inside the nozzle that results in a full cone pattern. Full cone nozzles produce large, evenly distributed drops and high flow rates. It is a low-drift nozzle and is often used to apply soil incorporated herbicides.

## 10.4 MAINTENANCE OF APPLIANCES

Dusters and sprayers if properly maintained last longer. The following precautions may be taken to maintain the appliances for longer and efficient service.

➤ **Precautions for maintaining sprayers**

- Select right kind of equipment and do not use leaky, defective equipment
- Separate equipment should be used for applying herbicides
- Only clean water should be used for preparing spray fluid
- A larger filter should be positioned between the mixer and sprayer tanks
- Pump out the residual liquid after each operation
- No spray mix should be left standing in the tank, hoses or nozzles as settling out of pesticides will cause blockages
- The sprayer should be washed thoroughly at the end of each day's spraying, several washings with small volume water is better
- Never plunge the piston rashly
- Lubricate the cup leather washer to keep it soft

- Avoid bending of hoses to prevent pressure reduction and damage
  - Each nozzle should be dismantled, the individual components should be removed, tip and cap should be cleaned and replaced
  - If nozzle blockage occurs while spraying the nozzle tip and filter should be removed and replaced by clean parts
  - In case of nozzle blockage a hard object such as a pin, nail or stiff wire should never be used as the orifice can be easily damaged
  - Nozzle should never be kept in mouth to blow through the orifice
- **Precautions for maintaining dusters**
- Blow out all the residual dust at the end of the each operation
  - Fill the hopper with dust without pressure
  - Gear box and gear teeth should be greased occasionally

## 10.5 AERIAL APPLICATION OF PESTICIDES

The aircrafts most commonly used for commercial application of insecticides are the biplanes, monoplanes and helicopters. Aerial spray application of concentrated chemicals at ultra low volume rates undiluted with water have been successfully employed in the control of mosquitoes and pests of paddy, wheat, sugarcane and cotton in India.

➤ **Principle of aerial application**

The spray droplets dispersed from an aircraft follow the path of air flowing around the aircraft. This air flow is produced by the aircraft when it tries to rise off the ground. During the take off the wings of the aero-plane press the air downwards this force imparts a downward motion to the air called down draft or down wash. Due to down draft the pressure below the wings becomes high and low above the wings. These forces drive the wind sideways towards the wing tips in rotary fashion. This movement of wind is called as wing tip vortex. The downwash helps carry the insecticide particles towards the crop while the wing tip vortices tend to deflect them sideways producing the swath. The plane flies lower and slower, the greater will be the downwash and stronger the wing tip vortices.

➤ **Factor affecting aerial application are**

**a. Particle size**

Larger the size of the particle more is deposit of insecticide. Larger particles have a tendency to fall vertically downwards and the smaller particles have tendency to deflect side ways.



**b. Wind velocity**

The wind velocity is inversely related to the particle size in case of dynamic catch (actual deposit of insecticide).

**c. Aircraft height**

The greater the height of an aircraft, the greater is the lateral dispersion (swath width) of the insecticide. The most suitable swath width to control field and vegetable crop pests is about 40ft, beyond which the insecticide deposit is not uniform to get good control.

**d. Air craft speed**

A decrease in the aircraft speed increases the wing tip vortex which in turn increases the swath width. It greatly affects the smaller particles.

**e. Meteorological conditions**

Wind flowing at right angle to the line of aircraft (turbulence) plays an important role in the distribution of insecticide. Turbulence is least in the early morning and just before the sun set during which the spraying should be carried out.

➤ **Equipments used for aerial application of insecticides**

- a. Air craft                      b. Spraying equipments
- c. Dusting equipments

**a. Air craft**

The air crafts most commonly used for commercial application of insecticides are the biplanes, monoplanes and helicopters. Helicopters are more advantageous since they can fly slowly and at lower heights, possess greater manoeuvrability, can land on any piece of flat ground.

**Desirable traits of applicator aircraft**

- Ability to carry a load of at least 35 to 40 % of its weight
- Ability to take off and climb to 50 ft with in ¼ mile with full load
- Safe operating speed of 60 to 100 mph
- Minimum safe flying speed of 45 mph
- Safety for pilot in case of crash
- Facility for easy and quick loading
- Maintenance and repair should be simple

**b. Spraying equipments**

The tank made of aluminium alloy. Spray pump corrosive resistant and wind

driven propeller. Spray boom made up of aluminium or steel tube. Twenty to 30 hollow cone or flat fan spray nozzles to provide droplet size of 50 – 200 microns.

**c. Dusting equipments**

The hopper made up of aluminium alloy. The agitator in the hopper is powered by a wind driven propeller. Dusting is usually done at a some what greater height than spraying.

## 10.6 ADVANTAGES AND DISADVANTAGES OF AERIAL APPLICATION

### Advantages

- Larger areas can be covered in lesser time period
- No mechanical damage to the crop
- It can be taken up on inaccessible areas like hilly, terrain, muddy, locust breeding areas in deserts, tall trees etc.
- It can be taken up in water filled fields for the treatment of mosquito larvae and aquatic weeds
- The cost of application per unit area is less when larger areas are covered compared to ground application
- The danger of exposure of toxic chemicals to operator is less
- It saves time and labour

### Disadvantages

- Problem of drift of toxic chemicals to distant places
- Undersurface of foliage is not well covered
- It depends on weather conditions like wind speed
- It is not profitable for small holdings
- There is high degree of risk involved both to the pilot and men on the ground due to low flying and possible crashes
- It is not possible in some areas because of tall trees, electric and telephone poles.



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| UNIT |
| 11   |

# Pests of Field Crops and their Management

## 11.1 DAMAGE AND MANAGEMENT OF PESTS OF CEREALS

### 1. Damage and management of major pests of rice

| Insect pest                                         | Family :<br>Order          | Damage symptoms                                                                                                                                                                                                                                                                                                 | Specific management practices                                                                                                                                                                                                                                                                                                                                |
|-----------------------------------------------------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Yellow stem borer,<br><i>Scirpophaga incertulas</i> | Pyalidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Monophagous pest of rice</li> <li>• Larvae bore into the central shoots and tillers and cause dead hearts in young plant and drying of panicle or white ear in older plants</li> </ul>                                                                                 | <ul style="list-style-type: none"> <li>• Clipping of tip of seedlings before transplanting to eliminate egg masses</li> <li>• Installation of pheromone traps for monitoring</li> <li>• Release of egg parasitoids, <i>Trichogramma japonicum</i> @ 50,000 / ha at weekly intervals</li> <li>• Need based application of triazophos or quinalphos</li> </ul> |
| Gall fly, <i>Orseolia oryzae</i>                    | Cecidomyiidae :<br>Diptera | <ul style="list-style-type: none"> <li>• Maggots enter into growing shoot and lacerate the leaf tissue</li> <li>• They produce galls on the basal portion of the central leaf or on the tillers</li> <li>• These galls become hollow giving a silvery shine called silver shoot / onion leaf in rice</li> </ul> | <ul style="list-style-type: none"> <li>• Removing of grasses and other alternate hosts</li> <li>• Careful timing of planting</li> <li>• Use only recommended doses of nitrogenous fertilizers</li> <li>• Uprooting stubbles with deep ploughing</li> </ul>                                                                                                   |

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|--------------------------------------------------------------------------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                          |                         |                                                                                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>soon after harvest</li> <li>Seedling root dip in 0.02 % chlorpyrifos</li> <li>Release of larval parasitoid, <i>Platygaster oryzae</i></li> </ul>                                                                                                                                                                                                                                                                           |
| Brown plant hopper, <i>Nilaparvata lugens</i>                            | Delphacidae : Hemiptera | <ul style="list-style-type: none"> <li>Nymphs and adults congregate at the base of the stem just above water level</li> <li>Heavy infestation causes yellowing and drying of plant leading to condition known as "hopper burn"</li> <li>It transmits grassy stunt virus</li> </ul> | <ul style="list-style-type: none"> <li>Closer spacing should be avoided</li> <li>Alternate wetting and drying of paddy fields</li> <li>Adopt planting with formation of alleys of 25 cm at intervals of 2 mts to provide good aeration and sunlight</li> <li>Use of light traps</li> <li>Release of <i>Cyrtorhinus lividipennis</i> @ 50 - 75 eggs per square meter at 10 days interval and 3 predatory spiders, <i>Lycosa pseudoannulata</i> per hill</li> </ul> |
| White backed plant hopper, <i>Sogatella furcifera</i>                    | Delphacidae: Hemiptera  | <ul style="list-style-type: none"> <li>Nymphs and adults suck cell sap particularly from the leaf sheath</li> <li>Symptoms start from leaf tips and move downwards</li> <li>Drying of young plants and in severe infestation, hopper burn symptoms are observed</li> </ul>         | <ul style="list-style-type: none"> <li>Closer spacing should be avoided</li> <li>Alternate wetting and drying of paddy fields</li> <li>Use of light traps</li> <li>Release of <i>Cyrtorhinus lividipennis</i> @ 50-75 eggs per square meter at 10 days interval</li> </ul>                                                                                                                                                                                        |
| Green leaf hopper, <i>Nephotettix nigropictus</i> and <i>N.virescens</i> | Cicadellidae: Hemiptera | <ul style="list-style-type: none"> <li>It lays eggs under the epidermis of leaf sheath</li> <li>Nymphs and adults suck the sap and infested leaves turn brown</li> <li>It is a vector of tungro</li> </ul>                                                                         | <ul style="list-style-type: none"> <li>Closer spacing should be avoided</li> <li>Avoid excessive use of nitrogenous fertilizers</li> <li>Maintain weed free</li> </ul>                                                                                                                                                                                                                                                                                            |

|                                                           |                           |                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                |
|-----------------------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                           |                           | virus                                                                                                                                                                                                                                                                             | field bunds <ul style="list-style-type: none"> <li>• Use of light traps</li> <li>• Release of <i>Cyrtorhinus lividipennis</i> @ 50-75 eggs per square meter at 10 days interval</li> </ul>                                                                     |
| Caseworm, <i>Nymphula depunctalis</i>                     | Pyraustidae: Lepidoptera  | <ul style="list-style-type: none"> <li>• Leaf cases hanging from rice leaf and cut leaf bits floating in water</li> <li>• The larvae feed by scraping the undersurface of the leaf blade leaving the upper epidermis intact, resulting in white patches on leaf blades</li> </ul> | <ul style="list-style-type: none"> <li>• Passing of the rope over the crop helps in dislodging of case worms</li> <li>• Draining of water from the field</li> <li>• Need based spray of quinalphos or monocrotophos</li> </ul>                                 |
| Leaf folder, <i>Cnaphalocris medinalis</i>                | Pyraustidae: Lepidoptera  | <ul style="list-style-type: none"> <li>• Larvae folds leaf marginally and feeds the fold leaves by scraping chlorophyll</li> <li>• Development of longitudinal white lines in leaves</li> <li>• The scraped leaves become membranous, turn white and finally wither</li> </ul>    | <ul style="list-style-type: none"> <li>• Judicious application of fertilizers</li> <li>• Light trapping of adults</li> <li>• Remove grass weeds from bunds</li> <li>• Need based application of quinalphos or triazophos</li> </ul>                            |
| Paddy earhead bug or gundhi bug, <i>Leptocorisa acuta</i> | Coreidae: Hemiptera       | <ul style="list-style-type: none"> <li>• Individual rice grains become white and chaffy</li> <li>• Buggy odour in rice fields during milky stage</li> <li>• Water spot appears at the point of puncture and becomes brown with center white</li> </ul>                            | <ul style="list-style-type: none"> <li>• Installation of light traps</li> <li>• Collection of adults with net and destroying them</li> <li>• Removal of weeds and other alternate hosts</li> <li>• Dusting of carbaryl or malathion 5% @ 25 kg / ha</li> </ul> |
| Rice hispa, <i>Diuraphis armigera</i>                     | Chrysomelidae: Coleoptera | <ul style="list-style-type: none"> <li>• White parallel streaks along leaf axis in rice (looks like ladder)</li> <li>• Grubs mine into leaves</li> </ul>                                                                                                                          | <ul style="list-style-type: none"> <li>• Clip off the infested leaf tips and destroy</li> <li>• Flood the nursery beds, sweep the</li> </ul>                                                                                                                   |

|                                                  |                            |                                                                                                                                                                                  |                                                                                                                                    |
|--------------------------------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
|                                                  |                            | <ul style="list-style-type: none"> <li>and cause blotches</li> <li>The damage starts in nursery and spreads to rice fields</li> </ul>                                            | <ul style="list-style-type: none"> <li>floating beetles and destroy</li> <li>Need based application of methyl parathion</li> </ul> |
| Rice thrips,<br><i>Stenchaetothrips biformis</i> | Thripidae:<br>Thysanoptera | <ul style="list-style-type: none"> <li>Marginal rolling in rice seedlings</li> <li>Nymphs and adults lacerate the leaf tissue and in severe infestation seedlings die</li> </ul> | <ul style="list-style-type: none"> <li>Dusting of carbaryl 5 % or malathion 5% @25 kg /ha</li> </ul>                               |
| Rice grass hopper,<br><i>Hieroglyphus banian</i> | Acrididae:<br>Orthoptera   | <ul style="list-style-type: none"> <li>Nibbling of rice ear head and defoliation leaving midrib in rice</li> <li>Formation of white ears (chaffyness)</li> </ul>                 | <ul style="list-style-type: none"> <li>Trimming the bunds</li> <li>Dust carbaryl 5 % or malathion 5% @25 kg /ha</li> </ul>         |

## 2. Damage and management of major pests of wheat

| Insect pest                                                         | Family :<br>Order            | Damage symptoms                                                                                                                                                                                                  | Specific management practices                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Termites,<br><i>Microtermes obesi</i><br><i>Odontotermes obesus</i> | Termitidae :<br>Isoptera     | <ul style="list-style-type: none"> <li>Workers feed in semicircular fashion on wheat leaf margin and roots partially eaten</li> <li>They attack standing crop especially during the period of drought</li> </ul> | <ul style="list-style-type: none"> <li>Frequent intercultural operations and irrigation before sowing</li> <li>Field sanitation, timely disposal of crop stubbles and undecomposed plant parts</li> <li>Destroy the termite bunds in and around the field and kill the queen</li> <li>Seed treatment with chlorpyrifos</li> </ul> |
| Stem borer,<br><i>Sesamia inferens</i>                              | Noctuidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>Formation of dead heart in the wheat central shoot</li> </ul>                                                                                                             | <ul style="list-style-type: none"> <li>Installation of pheromone traps for monitoring</li> <li>Release of egg parasitoids, <i>Trichogramma japonicum</i> @ 50,000/ ha at weekly intervals</li> <li>Need based application of triazophos or quinalphos</li> </ul>                                                                  |
| Wheat aphid,<br><i>Macrosiphum miscanthi</i>                        | Aphididae:<br>Hemiptera      | <ul style="list-style-type: none"> <li>They suck sap from the ears and tender leaves and decrease the yield of the crop</li> <li>Damage is severe in cold weather</li> </ul>                                     | <ul style="list-style-type: none"> <li>Need based spray of dimethoate or methyl oxydemeton</li> </ul>                                                                                                                                                                                                                             |
| Ghujhia weevil,<br><i>Tanymecus indicus</i>                         | Curculionidae:<br>Coleoptera | <ul style="list-style-type: none"> <li>The adults feed on leaves and tender shoots</li> <li>Weevils cut the seedlings at the ground level</li> </ul>                                                             | <ul style="list-style-type: none"> <li>Dusting of carbaryl 5 % or malathion 5% @ 25 kg / ha</li> </ul>                                                                                                                                                                                                                            |

### 3. Damage and management of major pests of sorghum

| Insect pest                                     | Family :<br>Order          | Damage symptoms                                                                                                                                                                                                                                  | Specific management practices                                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sorghum shoot fly,<br><i>Atherigona soccata</i> | Muscidae:<br>Diptera       | <ul style="list-style-type: none"> <li>• Maggots cause dead heart in young sorghum crop with more side tillers</li> </ul>                                                                                                                        | <ul style="list-style-type: none"> <li>• Early sowing of sorghum crop (June - July)</li> <li>• Growing of resistant varieties such as CHS - 7, CHS - 8 and IS - 5566</li> <li>• Higher seed rate</li> <li>• Fish meal trap</li> <li>• Application of granular insecticides such as carbofuran 3 G and phorate 10 G in whorls</li> </ul>                                                |
| Jowar stem borer,<br><i>Chilo partellus</i>     | Crambidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Dead heart in early stage of crop</li> <li>• Reddening of sorghum midrib</li> <li>• Pinholes on the whorl of newly opened leaves</li> </ul>                                                             | <ul style="list-style-type: none"> <li>• Uprooting and burning of the stubbles and chopping of stems</li> <li>• Need - based application of carbofuran 3 G @ 8 kg / ha</li> </ul>                                                                                                                                                                                                      |
| Sorghum midge,<br><i>Contarinia sorghicola</i>  | Cecidomyiidae :<br>Diptera | <ul style="list-style-type: none"> <li>• Maggots feed on the ovary</li> <li>• Pupal case observed in between glumes of sorghum grain</li> <li>• Red ooze comes out when the developing seed in the spikelets are pressed with fingers</li> </ul> | <ul style="list-style-type: none"> <li>• Collect and burn the infested panicles</li> <li>• Uniform sowing of similar maturity sorghum cultivars over large areas</li> <li>• Destruction of wild host plants including Johnson grass and sorghum volunteers</li> <li>• Growing resistant varieties like SPH 837,</li> <li>• Dusting of ear heads with endosulfan or carbaryl</li> </ul> |
| Earhead bug,<br><i>Calocoris angustatus</i>     | Miridae :<br>Hemiptera     | <ul style="list-style-type: none"> <li>• Nymphs and adults suck the milky juice of the grain prior to ripening</li> <li>• Severe infestation causes chaffyness of ear head</li> </ul>                                                            | <ul style="list-style-type: none"> <li>• Growing of open - type panicle varieties</li> <li>• Conserve reduviid bug and a lygaeid bugs</li> <li>• Dusting with carbaryl</li> </ul>                                                                                                                                                                                                      |



|                                        |                            |                                                                                                                                                                                                                              |                                                                                                                                                                                                                        |
|----------------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                        |                            |                                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>• Need based spray of malathion or endosulfan</li> </ul>                                                                                                                        |
| Shoot bug,<br><i>Perigrinus maidis</i> | Delphacidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>• Nymphs and adults suck the sap from leaves</li> <li>• The leaves become yellow and growth of plant is retarded</li> <li>• Infestation favours development of sooty mould</li> </ul> | <ul style="list-style-type: none"> <li>• Growing of open - type panicle varieties</li> <li>• Conserve natural enemies</li> <li>• Dusting of carbaryl</li> <li>• Need based spray of malathion or endosulfan</li> </ul> |

#### 4. Damage and management of major pests of maize

| Insect pest                                 | Family :<br>Order         | Damage symptoms                                                                                                                                                                      | Specific management practices                                                                                                                                                                                                                                                                                                                          |
|---------------------------------------------|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pink borer :<br><i>Sesamia inferens</i>     | Noctuidae<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Larvae chew the stem and epidermal layer of the sheath</li> <li>• Whorl feeding of larvae results in rows of oblong holes</li> </ul>        | <ul style="list-style-type: none"> <li>• Uprooting and burning of the stubbles and chopping of stems</li> <li>• Intercropping maize with soybean</li> <li>• Clipping of lower leaves of maize</li> <li>• Need - based application of carbofuran 3G @ 8 kg/ha</li> </ul>                                                                                |
| Maize stem borer,<br><i>Chilo partellus</i> | Pyralidae:<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Dead heart in early stage of crop</li> <li>• Reddening of sorghum midrib</li> <li>• Pinholes on the whorl of newly opened leaves</li> </ul> | <ul style="list-style-type: none"> <li>• Ploughing the field after harvest and destroy stubbles, weeds and other alternate hosts</li> <li>• Destruction of infected plant hand removal of dead hearts</li> <li>• Release of <i>Trichogramma chilonis</i> @1,00,000 per ha at 10-15 days interval</li> <li>• Installation of pheromone traps</li> </ul> |
| Cobworm, <i>Helicoverpa armigera</i>        | Noctuidae:<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars feed on tender grains and bores</li> </ul>                                                                                     | <ul style="list-style-type: none"> <li>• Deep summer ploughing</li> <li>• Installation of pheromone</li> </ul>                                                                                                                                                                                                                                         |

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|  |  | into cob<br>• It also feeds on silk and developing cobs | traps @10/ha for monitoring<br>• Erection of bird perches<br>• Spray of <i>Ha</i> -NPV at 250 LE with adjuvant like teepol, tinopal and jaggery etc.<br>• Spray of B.t.k. @1.5 kg/ha |
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## 11.2 DAMAGE AND MANAGEMENT OF MAJOR PESTS OF OILSEEDS

| Insect pest                                        | Family :<br>Order            | Damage symptoms                                                                                                            | Specific management practices                                                                                                                                                                                                                                                           |
|----------------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Groundnut</b>                                   |                              |                                                                                                                            |                                                                                                                                                                                                                                                                                         |
| Red hairy caterpillar, <i>Amsacta albistriga</i>   | Arctiidae :<br>Lepidoptera   | • Early instars skeletonize<br>• Late instars cause total defoliation leaving only midribs                                 | • Deep ploughing during April - May<br>• Intercropping with cow pea<br>• Set up the light traps to attract and kill the moths<br>• Vegetative trapping of migratory larvae by keeping twigs of <i>Jatropha</i> or <i>Calotropis</i><br>• Spray AaNPV @ 200LE/acre at third instar stage |
| Ground nut leaf miner, <i>Aproaerema modicella</i> | Gelechiidae :<br>Lepidoptera | • Larvae mines into the leaves<br>• White blotches are produced<br>• Webbing and drying of terminal leaf lets in groundnut | • Intercropping with soybean<br>• Installation of pheromone traps @ 25 / ha for monitoring<br>• Release <i>Trichogramma chilonis</i> @ 50000/ha, two times at 7-10 days interval followed by release of <i>Bracon hebetor</i> @ 5000/ha two times at 7-10 days                          |
| Groundnut aphid,                                   | Aphididae:                   | • Yellowing and distorted                                                                                                  | • Intercropping with cowpea                                                                                                                                                                                                                                                             |

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| <i>Aphis craccivora</i>                                                         | Hemiptera                 | <ul style="list-style-type: none"> <li>terminal shoots</li> <li>Adults and nymphs congregate on growing tips and foliage and desap plants resulting in chlorotic patches and curling of leaves</li> <li>Acts as vector of peanut stripe virus disease</li> </ul>                         | <ul style="list-style-type: none"> <li>Installation of yellow sticky traps</li> <li>Seed treatment with imidacloprid (5 g/kg seed)</li> <li>Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i> or <i>Syrphus / Scymnus</i> sp.</li> <li>Need based spray of monocrotophos or methyl demeton</li> </ul>                                                                                                                                                             |
| Root grubs, <i>Holotrichia consanguinea</i> , <i>H. serrata</i>                 | Melolonthidae: Coleoptera | <ul style="list-style-type: none"> <li>Wilting of groundnut plants in patches with damaged roots</li> </ul>                                                                                                                                                                              | <ul style="list-style-type: none"> <li>Field should be ploughed from the end of April to middle of May</li> <li>Mechanical control by large scale collection and destruction of adults at the time of their mass emergence</li> <li>Use of light traps and synthetic pheromone traps for monitoring</li> <li>Seed treatment with chlorpyriphos 20 EC or quinalphos 25 EC at 25 ml/kg</li> <li>Pre sowing soil treatment with phorate 10 G at 25 kg/ha or quinalphos 5 G at 30 kg/ha</li> </ul> |
| Groundnut thrips, <i>Frankliniella schultzei</i> , <i>Scirtothrips dorsalis</i> | Thripidae : Thysanoptera  | <ul style="list-style-type: none"> <li>Adults and nymphs lacerate and feed on leaf surface</li> <li>Yellow patches on upper surface and brown necrotic patches on lower surface and in severe the leaves curl up</li> <li>Acts as vector of peanut bud necrosis virus disease</li> </ul> | <ul style="list-style-type: none"> <li>Intercropping with cow pea</li> <li>Seed treatment with imidacloprid</li> <li>Release predators such as <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i></li> <li>Need based application of monocrotophos or metasystox</li> </ul>                                                                                                                                                                                                         |

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| Tobacco caterpillar,<br><i>Spodoptera litura</i> | Noctuidae:<br>Lepidoptera   | <ul style="list-style-type: none"> <li>Freshly hatched caterpillars feed gregariously by scraping the chlorophyll, later disperse, feed voraciously at night on the foliage</li> </ul>                          | <ul style="list-style-type: none"> <li>Growing of castor as trap crop</li> <li>Mechanical collection of egg masses</li> <li>Installation of light traps</li> <li>Installation of pheromone traps @10/ha for monitoring</li> <li>Release <i>Trichogramma chilonis</i> @ 50000/ha, two times at 7-10 days interval followed by release of <i>Bracon hebetor</i> @ 5000/ha two times at 7-10 days</li> <li>Spray of <i>SI-NPV</i> @ 250LE/ha</li> </ul> |
| Leaf hopper,<br><i>Empoasca kerri</i>            | Cicadellidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from young leaves</li> <li>The leaves later turn into yellowish brown and curl downwards</li> <li>'V' shaped yellowing at the tips</li> </ul> | <ul style="list-style-type: none"> <li>Setting of yellow sticky traps</li> <li>Intercropping with cow pea</li> <li>Seed treatment with imidacloprid</li> <li>Need based application of monocrotophos or metasystox</li> </ul>                                                                                                                                                                                                                        |
| Termites,<br><i>Odontotermes obesus</i>          | Termitidae:<br>Isoptera     | <ul style="list-style-type: none"> <li>Workers cause wilting and death of the plant</li> <li>Workers sometimes feed on pod</li> </ul>                                                                           | <ul style="list-style-type: none"> <li>Destroy the termite bunds in and around the field and kill the queen</li> <li>Deep ploughing before sowing and mulching of crops with mustard straws</li> <li>Application of the entomo-pathogenic fungus <i>Metarhizium anisopliae</i> at the time planting</li> <li>Use of chlorpyrifos 10 G as a soil treatment</li> <li>Seed dressing with chlorpyrifos 20 EC @ 12.5 ml / kg seed</li> </ul>              |

| Mustard                                              |                                |                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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| Mustard aphid,<br><i>Lipaphis erisymi</i>            | Aphididae :<br>Hemiptera       | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap from leaves and twigs</li> <li>• Curly leaf tip with poor pod set in mustard</li> </ul>                                                                                                                 | <ul style="list-style-type: none"> <li>• Avoid late sowing and excessive use of nitrogen fertilizers</li> <li>• The crop should be sown before 20th October</li> <li>• Three rounds of manual removal / clipping of aphid infested twigs</li> <li>• Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i> or <i>Syrphus</i> / <i>Scymnus</i> sp.</li> <li>• Need based spray of dimethoate 30 EC or methyl demeton 25 EC</li> </ul> |
| Mustard sawfly,<br><i>Athalia lugens proxima</i>     | Tenthredinidae:<br>Hymenoptera | <ul style="list-style-type: none"> <li>• Initially the larva nibbles leaves, later it feeds from the margins towards the midrib</li> <li>• They devour the epidermis of the shoot, resulting in drying up of seedlings and failure to bear seeds in older plants</li> </ul> | <ul style="list-style-type: none"> <li>• Summer ploughing to destroy the pupa</li> <li>• Early sowing should be done</li> <li>• Maintain clean cultivation</li> <li>• Apply irrigation in seedling stage is very crucial for sawfly management because most of the larvae die due to drowning effect</li> <li>• Use of bitter gourd seed oil emulsion as on anti-feedant</li> </ul>                                                                          |
| Castor                                               |                                |                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Bihar hairy caterpillar,<br><i>Spilosoma obliqua</i> | Arctiidae:<br>Lepidoptera      | <ul style="list-style-type: none"> <li>• Young larvae feed gregariously mostly on the under surface of the leaves</li> <li>• Caterpillars feed on leaves and in severe infestation the whole crop is defoliated.</li> <li>• Drying up of infected</li> </ul>                | <ul style="list-style-type: none"> <li>• Deep summer ploughing</li> <li>• Timely sowing and clean cultivation</li> <li>• Intercropping with pigeon pea at a row ratio of 2:1</li> <li>• Mechanical collection and destruction of larvae</li> <li>• Spray with NSKE 5%</li> <li>• Release parasitoids like</li> </ul>                                                                                                                                         |

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|                                                        |                          | leaves is the main symptom                                                                                                                                                                                       | <i>Charops obtusus</i>                                                                                                                                                                                                                                                                                                                     |
| Castor semilooper, <i>Achaea janata</i>                | Noctuidae: Lepidoptera   | <ul style="list-style-type: none"> <li>The caterpillars feed voraciously leaving only midribs</li> <li>With loss of foliage seed yield is reduced</li> </ul>                                                     | <ul style="list-style-type: none"> <li>Deep summer ploughing</li> <li>Collection of destruction of caterpillars</li> <li>Need based application of diazinon</li> </ul>                                                                                                                                                                     |
| Castor capsule borer, <i>Dichocrocis punctiferalis</i> | Pyralidae : Lepidoptera  | <ul style="list-style-type: none"> <li>Caterpillar feeds on the heads and cause webbing of capsule heads</li> </ul>                                                                                              | <ul style="list-style-type: none"> <li>Infested shoots and capsules are collected and destroyed</li> <li>Need based spray of carbaryl</li> </ul>                                                                                                                                                                                           |
| Whitefly, <i>Trialeurodes ricini</i>                   | Aleurodidae: Hemiptera   | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from lower part of leaves</li> </ul>                                                                                                           | <ul style="list-style-type: none"> <li>Setting up yellow pan sticky traps at various places</li> <li>Release <i>Chrysoperla carnea</i> @ 2 - 4 larvae/ plant</li> <li>Release <i>Cheilomenes sexmaculata</i> @ 1.5 lakh adults/ha at random</li> <li>Need based spray of methyl demeton or acephate or trizophos or profenophos</li> </ul> |
| Castor slug, <i>Parasa lepida</i>                      | Limacodidae: Lepidoptera | <ul style="list-style-type: none"> <li>Caterpillars feed gregariously by scarping the undersurface of the leaves</li> <li>Vitality of the plants is reduced</li> <li>Defoliation and drying of leaves</li> </ul> | <ul style="list-style-type: none"> <li>Need based application of endosulfan</li> </ul>                                                                                                                                                                                                                                                     |
| <b>Sunflower</b>                                       |                          |                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                            |
| Sunflower head borer, <i>Helicoverpa armigera</i>      | Noctuidae: Lepidoptera   | <ul style="list-style-type: none"> <li>The larva feeds on the developing seeds and bore the head</li> <li>The larva consumes leaf in early stage of growth and move towards the</li> </ul>                       | <ul style="list-style-type: none"> <li>Use of pheromone traps (4 traps / acre)</li> <li>Setting of light traps and bird perches @ 10/acre</li> <li>Use of <i>Ha-NPV</i> @250LE/ ha</li> </ul>                                                                                                                                              |

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|                                                                       |                         | capitulum and tunnel the head                                                                                                                                                                                                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>• Spray of B.t.k @1.5 kg/ha</li> <li>• Release parasitoids like <i>Trichogramma</i> spp. @ (50,000/acre), <i>Bracon</i> spp. and <i>Campoletis</i> spp.</li> </ul>                                                                                                                                               |
| <b>Sesame</b>                                                         |                         |                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                         |
| Leaf webber, roller and capsule borer, <i>Antigastra catalaunalis</i> | Pyalidae: Lepidoptera   | <ul style="list-style-type: none"> <li>• The young larvae roll together a few top leaves and feed</li> <li>• In the early stage of infestation, the plant dies without producing any branch or shoot</li> <li>• In later stage of attack, infested shoots stop growing</li> <li>• At flowering, larvae feed inside the flowers and on capsule formation, larvae bore into capsule and feed on developing seeds</li> </ul> | <ul style="list-style-type: none"> <li>• Early sowing of crop</li> <li>• Intercrop with mungbean, pearl millet, urdbean and moth bean</li> <li>• Removal of larvae from the leaf webs during the initial stages of plant growth</li> <li>• Need based application of quinalphos or deltamethrin</li> </ul>                                              |
| Hawk moth, <i>Acherontia styx</i>                                     | Sphingidae: Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars feed on the leaves and defoliate the plant</li> <li>• It remains active through out the crop season</li> </ul>                                                                                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>• Deep ploughing exposes the pupae for predation to insectivorous birds</li> <li>• Hand picking collection and destruction of caterpillars</li> <li>• Use egg parasite <i>Anastatus acherontiae</i></li> </ul>                                                                                                   |
| Linseed gall fly, <i>Dasyneura sesami</i>                             | Cecidomyiidae: Diptera  | <ul style="list-style-type: none"> <li>• Maggots feed on buds and flowers</li> <li>• No formation of pods</li> </ul>                                                                                                                                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>• Avoid late sowing</li> <li>• Setting up of light traps for killing the adults</li> <li>• The infested buds should be removed and destroyed</li> <li>• Use larval parasite <i>Pteromalus fasciatus</i></li> <li>• Need based spray at bud initiation stage with dimethoate 0.03% or endosulfan 0.07%</li> </ul> |

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| Sesame gall fly,<br><i>Asphondylia sesami</i>                         | Cecidomyiidae:<br>Diptera | <ul style="list-style-type: none"> <li>• Maggots feed inside the floral bud leading to formation of gall like structure which does not develop in to flower /capsules</li> <li>• The affected buds wither and drop</li> </ul> | <ul style="list-style-type: none"> <li>• Use resistant tolerant varieties such as RT - 46, Swetha Til, RT - 103, RT - 108, RT - 125 and RT - 127</li> <li>• Intercrop with mung bean, pearl millet and groundnut</li> <li>• Clip the galls, pick and burn the shed buds</li> <li>• Use larval parasitoids such as <i>Eurytoma dentipectus</i> and <i>Bracon hebetor</i></li> </ul> |
| <b>Safflower</b>                                                      |                           |                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                    |
| Safflower caterpillar,<br><i>Perigaea capensis</i>                    | Noctuidae:<br>Lepidoptera | <ul style="list-style-type: none"> <li>• The larva feeds on the leaves and sometimes on capitulum</li> <li>• It also feeds on bracts, flowers and capsules</li> </ul>                                                         | <ul style="list-style-type: none"> <li>• Intercropping with non-host crop like wheat should be done</li> <li>• Excessive application of nitrogen should be avoided</li> <li>• The caterpillars should be hand collected and then killed</li> <li>• Release of braconids and eulophids</li> </ul>                                                                                   |
| Capsule fly/<br>Safflower bud fly,<br><i>Acanthiophilus helianthi</i> | Tephritidae:<br>Diptera   | <ul style="list-style-type: none"> <li>• Maggots feed on soft parts of the capsules and thalamus</li> <li>• The infested buds rot and give an offensive smelling fluid</li> </ul>                                             | <ul style="list-style-type: none"> <li>• Timely sowing of the crop</li> <li>• Clean cultivation</li> <li>• Early removal and destruction of infected flower buds</li> <li>• Use of light traps</li> </ul>                                                                                                                                                                          |
| Safflower, aphid,<br><i>Uroleucon compositae</i>                      | Aphididae:<br>Hemiptera   | <ul style="list-style-type: none"> <li>• Nymphs and adults found in groups and suck the sap from leaves and capsules</li> </ul>                                                                                               | <ul style="list-style-type: none"> <li>• Installation of yellow sticky traps</li> <li>• Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i> or <i>Syrphus / Scymnus</i> sp.</li> <li>• Need based spray of monocrotophos or methyl demeton</li> </ul>                                                                                                   |



### 11.3 DAMAGE AND MANAGEMENT OF MAJOR PESTS OF PULSES

| Insect pest                                    | Family :<br>Order          | Damage symptoms                                                                                                                                                                                                                                                   | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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| <b>Pigeon pea</b>                              |                            |                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Gram pod borer,<br><i>Helicoverpa armigera</i> | Noctuidae:<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Small larvae eat up the green portion of the plant</li> <li>• The larger larvae eat up the floral parts, flowers, leaves and pods</li> <li>• Circular bore holes on pulse pods plugged by the head of a larva</li> </ul> | <ul style="list-style-type: none"> <li>• Use of short duration and resistant varieties</li> <li>• Deep summer ploughing</li> <li>• Sowing should be done by the end of June to avoid pod borer attack</li> <li>• Installation of pheromone traps @10/ha for monitoring</li> <li>• Physical shaking of pigeon pea plants to dislodge larvae</li> <li>• Erection of bird perches</li> <li>• Spray of <i>Ha</i>-NPV at 500 LE with adjuvant like teepol, tinopal and jaggery etc.</li> </ul> |
| Red gram pod borer, <i>Etiella zinckenella</i> | Phycitidae:<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Larvae bores into the pods and feeds on the developing seeds</li> <li>• Faecal pellets are seen inside the damaged pods</li> </ul>                                                                                       | <ul style="list-style-type: none"> <li>• Spraying of endosulfan 35 EC 0.07% ( 2ml of 35 EC/ lit. of water) or monocrotophos 36SL</li> </ul>                                                                                                                                                                                                                                                                                                                                               |
| Gram cut worm, <i>Agrotis ipsilon</i>          | Noctuidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• The caterpillar hide during the day and come out in the evening for damage</li> <li>• Irregular bore hole in red gram pod it also feeds on flower buds and seeds</li> </ul>                                              | <ul style="list-style-type: none"> <li>• Deep summer ploughing</li> <li>• Use well decomposed organic manure</li> <li>• Adapt crop rotation</li> <li>• Intercropping with wheat or linseed or mustard reduces infestation</li> <li>• In the early stages pick the insects and destroy</li> <li>• Conserve natural enemies such as Braconids, <i>Microgaster</i> sp.</li> </ul>                                                                                                            |

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| Red gram plume moth, <i>Exelastis atomosa</i> | Pterophoridae: Lepidoptera | <ul style="list-style-type: none"> <li>Hairy larva found inside the irregular bore hole in red gram pod it also feeds on flower buds and seeds</li> <li>The larvae excretes inside the damaged grain and pods and due to this fungus develops in it</li> </ul>                                                                       | <ul style="list-style-type: none"> <li>Timely sowing of the crop</li> <li>Adoption of mixed or intercropping with non host plants</li> <li>Maintaining complete field sanitation</li> <li>Do not repeat sowing of pigeon pea crop in same field</li> <li>Need based spray of endosulphan 35 EC or monocrotophos 36 SL</li> </ul> |
| Red gram pod fly, <i>Melanagromyza obtusa</i> | Agromyzidae: diptera       | <ul style="list-style-type: none"> <li>Pin head sized bore hole near the septum which provides an emergence “window” through which the adults exit the pod</li> <li>Maggots feed on the seeds as internal borer and shrivelling of developing pulse seeds</li> <li>Damaged grains do not mature and loose their viability</li> </ul> | <ul style="list-style-type: none"> <li>Grow resistant varieties</li> <li>Intercropping with jowar, maize or groundnut etc.</li> <li>Crop rotation</li> <li>Conserve the parasite, <i>Ormyrus</i> sp.</li> </ul>                                                                                                                  |
| Blister beetle, <i>Mylabris pustulata</i>     | Meloidae: Coleopteran      | <ul style="list-style-type: none"> <li>Flowers partially eaten and petals are damaged</li> <li>When distributed the beetles exude an acrid yellow fluid called cantharidin which causes blisters on tender skin</li> </ul>                                                                                                           | <ul style="list-style-type: none"> <li>Avoid excess application of nitrogen</li> <li>Manual collection or collection with insect net and killing of adults in kerosenized water</li> <li>Need based spray of carbaryl and fenthion</li> </ul>                                                                                    |
| Spotted pod borer, <i>Maruca testulalis</i>   | Pyraustidae : Lepidoptera  | <ul style="list-style-type: none"> <li>The larva webs together the leaves, buds and pods and feeds inside these webs</li> <li>The caterpillar also bores into pods and eats up the ripening seeds</li> <li>A crown mass of</li> </ul>                                                                                                | <ul style="list-style-type: none"> <li>Timely sowing should be done preferably up to first quarter of July</li> <li>Excess application of nitrogen should be avoided</li> <li>Water logging should be prevented</li> </ul>                                                                                                       |

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|                                                 |                          | excrement is seen at the entrance into the larval burrow                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>• Conserve ants and praying mantids</li> </ul>                                                                                                                                                                                             |
| Pod bug, <i>C lavigralla gibbosa</i>            | Coreidae : Hemiptera     | <ul style="list-style-type: none"> <li>• Nymphs and adults suck the sap from tender shoots and pods</li> <li>• The seeds become shriveled with dark patches and lose germination</li> </ul>                                                                           | <ul style="list-style-type: none"> <li>• Use of medium duration varieties JA-4 or JKM-7</li> <li>• Need based spray of endosulfan or monocrotophos</li> </ul>                                                                                                                     |
| Pod borer, <i>Adisura atkinsoni</i>             | Noctuidae : Lepidoptera  | <ul style="list-style-type: none"> <li>• Caterpillars bore into pods and damage seeds</li> </ul>                                                                                                                                                                      | <ul style="list-style-type: none"> <li>• Timely sowing of the crop</li> <li>• Deep summer ploughing</li> <li>• Need based spray of endosulfan or cypermethrin</li> </ul>                                                                                                          |
| Pulse beetle <i>Callasobruchus chinensis</i>    | Bruchidae: Coleoptera    | <ul style="list-style-type: none"> <li>• Grubs feed on the inner content of seed</li> <li>• Infested stored seed can be recognized by the white eggs on the seed surface and the round exit holes</li> </ul>                                                          | <ul style="list-style-type: none"> <li>• Dry the pods to optimum kernel moisture level of about 7 %</li> <li>• Fumigation with aluminum phosphide</li> </ul>                                                                                                                      |
| <b>Soybean</b>                                  |                          |                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                   |
| Soybean leaf miner, <i>Aproaerema modicella</i> | Gelechiidae: Lepidoptera | <ul style="list-style-type: none"> <li>• Larvae mines into the leaves and produces white blotches and in severe infestation the field gives burnt appearance</li> </ul>                                                                                               | <ul style="list-style-type: none"> <li>• Growing groundnut as trap crop</li> <li>• Installation of pheromone traps @25 /ha</li> <li>• Need based spray of endosulfan or quinalphos</li> </ul>                                                                                     |
| Soybean Girdle beetle, <i>Oberea brevis</i>     | Cerambycidae: Coleoptera | <ul style="list-style-type: none"> <li>• The larvae bores the stem of soybean and tunnel is formed inside the stem</li> <li>• The leaves of plant of infected portion are unable to get the nutrient and are dried up</li> <li>• In later stages the plant</li> </ul> | <ul style="list-style-type: none"> <li>• Deep summer ploughing</li> <li>• Destroy crop residues and avoid excess nitrogenous fertilizers</li> <li>• Sowing of tolerant varieties like Ahilya-2 (NRC 12), Ahilya-3 (NRC 7), Gaurav (JS-72-44), Indira soy 9 and RAUS 5.</li> </ul> |

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|                                                |                        | is cut at about 15 to 25 cms above the ground                                                                                                                                                                      | <ul style="list-style-type: none"> <li>• Use of optimum seed rate (70-100 kg/ha)</li> </ul>                                                                                                                                                                                                                                                                                        |
| Bean aphid, <i>Aphis craccivora</i>            | Aphididae: Hemiptera   | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap</li> <li>• Excretion of honey dew attracts sooty mold</li> </ul>                                                                               | <ul style="list-style-type: none"> <li>• Avoid late sowing and excessive use of nitrogen fertilizers</li> <li>• Seed treatment with imidacloprid (5 g/kg seed)</li> <li>• Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septempunctata</i> or <i>Syrphus</i> / <i>Scymnus</i> sp.</li> <li>• Need based spray of dimethoate 30 EC or methyl demeton 25 EC</li> </ul> |
| Field bean pod borer, <i>Adisura atkinsoni</i> | Noctuidae: Lepidoptera | <ul style="list-style-type: none"> <li>• The larvae feed on the flowers and bore into pods and feed on developing pods</li> </ul>                                                                                  | <ul style="list-style-type: none"> <li>• Need based spray of endosulfan or cypermethrin</li> </ul>                                                                                                                                                                                                                                                                                 |
| <b>Cowpea</b>                                  |                        |                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                    |
| Bean fly, <i>Ophiomyia phaseoli</i>            | Agromyzidae: Diptera   | <ul style="list-style-type: none"> <li>• Leaves turn yellow giving plant a dry appearance</li> <li>• Infested stems turn brown, become swollen and break down</li> <li>• Pods with small seeds or empty</li> </ul> | <ul style="list-style-type: none"> <li>• Soil application of phorate</li> <li>• Need based spray of monocrotophos or oxydemeton methyl</li> </ul>                                                                                                                                                                                                                                  |
| Spotted pod borer, <i>Maruca testuralis</i>    | Pyralidae: Lepidoptera | <ul style="list-style-type: none"> <li>• The larvae web together the flowers and feed on them</li> <li>• Larvae bore into the pods and feed on seeds</li> </ul>                                                    | <ul style="list-style-type: none"> <li>• Destruction of infested plants</li> <li>• Collection and destruction of caterpillars</li> <li>• Installation of pheromone traps</li> <li>• Need based spray of endosulfan or quinalphos</li> </ul>                                                                                                                                        |

### 11.4 DAMAGE AND MANAGEMENT OF MAJOR PESTS OF FIBRE CROPS

| Insect pest                                     | Family :<br>Order            | Damage symptoms                                                                                                                                                                                                                                                     | Specific management practices                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Cotton</b>                                   |                              |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                     |
| Cotton leaf hopper,<br><i>Amrasca biguttula</i> | Cicadellidae :<br>Hemiptera  | <ul style="list-style-type: none"> <li>Both adults and nymphs suck sap from the underside of the leaves and devitalize the plants</li> <li>Leaves turn pale, red rust, curls downwards and dry up when infestation is severe</li> </ul>                             | <ul style="list-style-type: none"> <li>Grow cowpea or soybean as an intercrop</li> <li>Use yellow sticky traps</li> <li>Seed treatment with imidacloprid @ 5g / kg seeds</li> <li>Release of predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i></li> <li>Need based spray of methyl demeton 25 EC or dimethoate 30 EC</li> </ul>                |
| Cotton aphid,<br><i>Aphis gossypii</i>          | Aphididae :<br>Hemiptera     | <ul style="list-style-type: none"> <li>Both adults and nymphs suck sap from the tender leaves, twigs and buds, and weaken the plants</li> <li>Leaf crumbling and downwards curling</li> <li>Excretes honeydew which encourages development of sooty mold</li> </ul> | <ul style="list-style-type: none"> <li>Avoid late sowing and excessive use of nitrogen fertilizers</li> <li>Seed treatment with imidacloprid (5 g/kg seed)</li> <li>Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i> or <i>Syrphus / Scymnus</i> sp.</li> <li>Need based spray of dimethoate 30 EC or methyl demeton 25 EC</li> </ul> |
| Cotton leaf roller,<br><i>Sylepta derogate</i>  | Pyraustidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>Cotton leaves rolled like a trumpet i.e. it rolls leaves in a funnel like shape and feeds by staying inside the funnel</li> </ul>                                                                                            | <ul style="list-style-type: none"> <li>Clean cultivation and destruction of crop residues</li> <li>Plough deeply to expose the hibernating larvae / pupae.</li> <li>Avoid late sowing of the crop</li> </ul>                                                                                                                                                        |

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|                                                |                           |                                                                                                                                                                                                                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>• Need based spray of quinalphos or cypermethrin</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Whitefly, <i>Bemisia tabaci</i>                | Aleyradidae: Hemiptera    | <ul style="list-style-type: none"> <li>• Nymphs and adults suck plant sap leading to premature defoliation</li> <li>• Chlorotic spots develop on leaves and in severe cases the vein becomes translucent, thickened and in many cases it drops off prematurely</li> <li>• Development of sooty mould due to honeydew secretion</li> <li>• The insects transmits leaf curl virus (CLCV) disease</li> </ul> | <ul style="list-style-type: none"> <li>• Setting up yellow pan sticky traps at various places</li> <li>• Seed treatment with imidacloprid @ 5g/kg seeds</li> <li>• Release <i>Chrysoperla carnea</i> @ 2 -4 larvae/plant</li> <li>• Release <i>Cheilomenes sexmaculata</i> @ 1.5 lakh adults/ha at random</li> <li>• Need based spray of methyl demeton 25 C or aephate or trizophos or profenophos</li> </ul>                                                                                                                               |
| Cotton stem weevil, <i>Pempherelus affinis</i> | Curculionidae: Coleoptera | <ul style="list-style-type: none"> <li>• Gall like swelling near the collar region of cotton stem</li> <li>• Grub tunnels into the stem resulting in breakage and death of the plant</li> </ul>                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>• Collection and destruction of affected plants</li> <li>• Need based application of chlorpyrifos with water @ 5 litres/ha</li> </ul>                                                                                                                                                                                                                                                                                                                                                                 |
| American bollworm, <i>Helicoverpa armigera</i> | Noctuidae: Lepidoptera    | <ul style="list-style-type: none"> <li>• Larvae feeds voraciously on leaves and flowers initially</li> <li>• They bore in to the square/bolls and seeds with its head thrust into the boll, leaving the rest of the body outside</li> <li>• The entry holes are large and circular at the base of the boll</li> </ul>                                                                                     | <ul style="list-style-type: none"> <li>• Plough deeply, clean cultivation to expose the resting pupae</li> <li>• Follow crop rotation</li> <li>• Grow marigold or pigeonpea as trap</li> <li>• Release of egg parasitoids like <i>Trichogramma chilonis</i> or <i>T. brasielenis</i> @ 1,50,000 /ha from 45th day onwards at 10-15 days interval</li> <li>• Release of the predators <i>Chrysoperla carnea</i> or <i>Scymnus sp.</i> or <i>Eulophids</i></li> <li>• Spray Ha-NPV @ 250 LE/ha</li> <li>• Apply B.t.k. @ 1.5 kg/ha.</li> </ul> |

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| Spotted bollworm,<br><i>Earias insulana</i>        | Noctuidae:<br>Lepidoptera    | <ul style="list-style-type: none"> <li>• The caterpillars bore into the growing shoots, buds, flowers and bolls</li> <li>• The attacked shoots wither, droop and ultimately die</li> <li>• Flowers and buds drop off</li> <li>• Holes on damaged bolls are plugged with excreta</li> <li>• Infested bolls do not shed, open prematurely &amp; the quality of the lint is spoiled due to rot setting</li> </ul>                                               | <ul style="list-style-type: none"> <li>• Deep ploughing to expose resting pupae</li> <li>• Avoid use of nitrogen fertilizers at the reproductive stage</li> <li>• Use resistant varieties</li> <li>• Planting trap crop of okra</li> <li>• Release egg parasitoid <i>Trichogramma chilonis</i>, <i>T. brasiliensis</i>, and larval parasitoids <i>Chelonus blackburni</i> or <i>Bracon brevicornis</i> or <i>Apanteles</i> sp. at 35 to 70 days</li> </ul> |
| Pink boll worm,<br><i>Pectinophora gossypiella</i> | Gelechiidae:<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Larvae feeds on flower buds, flowers and bolls</li> <li>• The holes of entry close down by excreta of larvae which are feeding inside the seed kernels</li> <li>• They cut window holes in the two adjoining seeds thereby forming “double seeds” and damage them</li> <li>• The attacked buds and immature bolls drop off</li> <li>• Lint is destroyed, ginning percentage and oil content are impaired</li> </ul> | <ul style="list-style-type: none"> <li>• Clean cultivation and destruction of crop residues</li> <li>• Plough deeply to expose the hibernating larvae / pupae</li> <li>• Avoid late sowing of the crop</li> <li>• Use of tolerant varieties (Khandwa-2, JKH-1, Abadita, LH 900, Sujay and Desi cotton)</li> <li>• Installation of pheromone traps @10/ha for monitoring</li> </ul>                                                                         |
| Mealy bug,<br><i>Phenacoccus solenopsis</i>        | Pseudococcidae:<br>Hemiptera | <ul style="list-style-type: none"> <li>• They suck a large amount of sap from leaves and stems depriving plants of essential nutrients showing the symptoms like retarded growth, late opening of bolls and total drying of the plant</li> </ul>                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>• Field sanitation, uprooting of infested plants</li> <li>• Use of effective biological control agents such as <i>Aenasius bambawalei</i>, <i>Anagyrus kamali</i>, <i>Cryptolaemus montrouzieri</i> and <i>Chrysoperla carnea</i></li> <li>• Dusting of methyl parathion 2 per cent or spraying of profenophos 50 EC or chlorpyrifos 25 EC</li> </ul>                                                               |

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| Jute                                            |                              |                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------------|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Jute semilooper,<br><i>Anomis sabulifera</i>    | Noctuidae:<br>Lepidoptera    | <ul style="list-style-type: none"> <li>The attack is severe on half grown plants which are 1 meter high</li> <li>Top 7 - 9 leaves are damaged and plant growth is effected</li> <li>Drastic reduction in yield of fibre</li> </ul>                                                              | <ul style="list-style-type: none"> <li>Ploughing the infested field after harvest</li> <li>Dislodging of caterpillars into kerosene water by drawing a rope across the young crop</li> <li>Need based spray of fenitrothion or endosulfan</li> </ul>                                                                                |
| Jute stem girdler,<br><i>Nupserha bicolor</i>   | Lamiidae:<br>Coleoptera      | <ul style="list-style-type: none"> <li>Breakage in fibre length at several places due to oviposition</li> <li>Quality of fibre and yield is effected</li> </ul>                                                                                                                                 | <ul style="list-style-type: none"> <li>Growing of resistant species of jute</li> <li>Mixing of phorate with top soil followed by irrigation</li> </ul>                                                                                                                                                                              |
| Jute stem weevil,<br><i>Apion corchori</i>      | Apionidae:<br>Coleoptera     | <ul style="list-style-type: none"> <li>Quality of the fibre is effected by weevils making oviposition holes</li> </ul>                                                                                                                                                                          | <ul style="list-style-type: none"> <li>Collecting and destroying the stubble after harvest</li> <li>Removal and destruction of infested plants at the time of thinning</li> <li>Need based spray of carbaryl</li> </ul>                                                                                                             |
| Indigo caterpillar,<br><i>Spodoptera exigua</i> | Noctuidae:<br>Lepidoptera    | <ul style="list-style-type: none"> <li>Feeding of larvae give webbed appearance of the crop</li> <li>Caterpillars feed voraciously on the foliage</li> </ul>                                                                                                                                    | <ul style="list-style-type: none"> <li>Late sowing</li> <li>Collection and destruction of egg masses and caterpillars feeding with in the webs</li> <li>Need based spray of fenitrothion or endosulfan</li> </ul>                                                                                                                   |
| Jute mealy bug,<br><i>Phenococcus hirsutus</i>  | Pseudococcidae:<br>Hemiptera | <ul style="list-style-type: none"> <li>Nymphs and adults suck sp from apical parts</li> <li>Plants become stunted and show bushy top symptoms</li> <li>Petiole becomes shortened, lamina crumples and inter-nodal length is reduced</li> <li>Fibre deterioration and yield reduction</li> </ul> | <ul style="list-style-type: none"> <li>Field sanitation, uprooting of infested plants</li> <li>Dusting of methyl parathion 2 per cent or spraying of profenophos 50 EC or chlorpyriphos 25 EC</li> <li>Use of effective biological control agents such as <i>Cryptolaemus montrouzieri</i> and <i>Chrysoperla carnea</i></li> </ul> |



| Sunhemp                                               |                          |                                                                                                                                                         |                                                                                                                                                                                                              |
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| Sunhemp hairy caterpillar, <i>Utethesia pulchella</i> | Arctiidae: Lepidoptera   | <ul style="list-style-type: none"> <li>• Caterpillars feed on the leaves and causes reduction in seed production</li> </ul>                             | <ul style="list-style-type: none"> <li>• Collecting the moths with nets during day time</li> <li>• Hand picking and killing of caterpillars</li> <li>• Need based spray of endosulfan or carbaryl</li> </ul> |
| Sunhemp stem borer, <i>Enarmonia pseudonectis</i>     | Tortricidae: Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars feed on the leaves and pods</li> <li>• Formation of small galls or swellings by larvae</li> </ul> | <ul style="list-style-type: none"> <li>• Burning of infested plants</li> <li>• Hand picking and killing of caterpillars</li> <li>• Need based spray of endosulfan or carbaryl</li> </ul>                     |
| Sunhemp capsid, <i>Ragnus importunitas</i>            | Miridae: Hemiptera       | <ul style="list-style-type: none"> <li>• Nymphs feed the plants</li> <li>• Infested plants become pale and unhealthy</li> </ul>                         | <ul style="list-style-type: none"> <li>• Collection of bugs with nets or sticky boards</li> <li>• Need based spray of malathion or carbaryl</li> </ul>                                                       |

## 11.5 DAMAGE AND MANAGEMENT OF MAJOR INSECT PESTS OF SUGARCANE

| Insect pest                                      | Family :<br>Order            | Damage symptoms                                                                                                                                                                                                                                                                                                                          | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Early shoot borer,<br><i>Chilo infuscatellus</i> | Pyralidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>Cutting of the growing shoot and formation of dead heart</li> </ul>                                                                                                                                                                                                                               | <ul style="list-style-type: none"> <li>Early planting of setts</li> <li>Setts showing borer damage should be discarded</li> <li>Trash mulching and earthing up</li> <li>Whorl application of lindane</li> <li>Installation of pheromone traps</li> <li>Application of carbaryl granules in the furrows</li> <li>Release of egg parasitoids, <i>Trichogramma chilonis</i> @ 1,00,000 / ha</li> <li>Spray Granulosis virus (GV) @ 250 LE / ha</li> </ul> |
| Top shoot borer,<br><i>Scirpophaga nivella</i>   | Pyraustidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>Shot holes are seen on leaves once they open</li> <li>Bunchy top appearance in grown up sugarcane due to formation of side shoots</li> <li>The damage is characterized by the appearance of a dried-up central shoot which is greyish-white in colour and commonly known as dead-heart</li> </ul> | <ul style="list-style-type: none"> <li>Collection and destruction of egg masses</li> <li>Cut infested shoots from the top and destroy the caterpillars</li> <li>Setts showing borer damage should be discarded</li> <li>Need based application of carbofuran or phorate at the base of the shoots</li> <li>Release of egg parasitoids, <i>Trichogramma chilonis</i> @1,00, 000/ha</li> <li>Spray Granulosis virus (GV) @ 250 LE/ha</li> </ul>          |
| Gurdaspur borer, <i>Acigona steniella</i>        | Pyralidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>The young larvae feed gregariously in the top portion of the canes by</li> </ul>                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>Rogue out the canes showing withered tops</li> <li>Do not ratoon heavily</li> </ul>                                                                                                                                                                                                                                                                                                                             |

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|                                                      |                            | <p>making spiral galleries and later by boring into the cane</p> <ul style="list-style-type: none"> <li>• Dried cane tops are seen in the field</li> </ul>                                                                                                                                                            | <p>affected crop</p> <ul style="list-style-type: none"> <li>• Destroy the stubbles</li> <li>• Release of <i>T. chilonis</i> at 50,000 per ha at 10 days interval</li> </ul>                                                                                                                                                                                                                                                                              |
| Internode borer, <i>Chilo sacchariphagus indicus</i> | Pyralidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Bore holes on sugarcane internodes</li> <li>• Entry holes plugged with excreta</li> <li>• Larval feeding causes the tissues turn red</li> </ul>                                                                                                                              | <ul style="list-style-type: none"> <li>• Remove damage cane tops in the initial stage of the attack, before the caterpillars migrate to fresh canes</li> <li>• Release of <i>Sturmiopsis inferens</i></li> <li>• Installation of pheromone traps</li> <li>• Catch the moths using light - traps</li> <li>• Release of egg parasitoids, <i>Trichogramma chilonis</i> @1,00,000 / ha</li> <li>• Application of carbaryl granules in the furrows</li> </ul> |
| Stalk borer, <i>Chilo auricilius</i>                 | Pyralidae:<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Bores into the cane and feeds on the inner content</li> <li>• The caterpillars feed on the unopened leaves and then bore into the stem and make a long tunnel by feeding on the internal tissue</li> <li>• The attacked cane invariably shows signs of dead-heart</li> </ul> | <ul style="list-style-type: none"> <li>• Provide proper drainage in the field since the damage is severe in water-logged fields due to the lodging of canes</li> <li>• Avoid taking a ratoon crop</li> <li>• Restrict the movement of infested canes</li> <li>• Release of egg parasitoids, <i>Trichogramma chilonis</i> @1,00, 000/ha</li> <li>• Installation of pheromone traps</li> </ul>                                                             |
| Root borer, <i>Emmalocera depressella</i>            | Pyralidae:<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Caterpillars eat inside the lower stem</li> <li>• The damage is characterised by the appearance of a dried-up central shoot and formation of dead heart</li> <li>• Dead hearts are not easily pulled out</li> </ul>                                                          | <ul style="list-style-type: none"> <li>• Avoid ratooning in the case of severe infestation</li> <li>• Dig out and burn the stubbles after the harvest</li> <li>• Cut the infested shoots and destroy them</li> <li>• Release of egg parasitoid <i>Trichogramma chilonis</i></li> </ul>                                                                                                                                                                   |

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| Root grub,<br><i>Holotrichia serrata</i>           | Melolonthidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>• They feed on live roots and cause the cane dries up</li> </ul>                                                                                                                                                              | <ul style="list-style-type: none"> <li>• Deep summer ploughing</li> <li>• Soil incorporation of <i>Metarrhizium anisopliae</i> <math>2.5 \times 10^{10}</math> spores/m<sup>3</sup></li> <li>• Soil incorporation of phorate or carbofuran granules</li> </ul>                                                                                                                                                                                                               |
| Termites,<br><i>Odontotermes obesus</i>            | Termitidae :<br>Isoptera      | <ul style="list-style-type: none"> <li>• Workers attack the newly planted setts and affect germination</li> <li>• Gappy appearance at seedling stage</li> <li>• Sugarcane setts filled with soil</li> </ul>                                                          | <ul style="list-style-type: none"> <li>• Frequent intercultural operations and irrigation before sowing</li> <li>• Destroy the termite bunds in and around the field and kill the queen</li> <li>• Setts treatment with imidacloprid</li> <li>• Need based application of chlorpyrifos</li> </ul>                                                                                                                                                                            |
| Sugarcane scale, <i>Melanaspis glomerata</i>       | Diaspididae :<br>Hemiptera    | <ul style="list-style-type: none"> <li>• Shriveling and drying of canes with reduced internodes</li> <li>• Infested crop loses its vigour, canes shrivel, growth is stunted and the internodal length is reduced very much</li> </ul>                                | <ul style="list-style-type: none"> <li>• Avoid seed material from the infested field</li> <li>• Stripping of cane leaves minimizes the attack</li> <li>• Ratooning should be avoided in the case of severe infestation</li> <li>• Trash and other crop residues of the infested crop must be burnt</li> <li>• Release of <i>Pharoscymus horni</i> @ 1500 adults beetles or grubs</li> <li>• Dipping the setts in 0.1 % malathion 0.08 % dimethoate for 15 minutes</li> </ul> |
| Sugarcane mealybug, <i>Saccharicoccus sacchari</i> | Pseudococcidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>• Nymphs and adults stick to the nodes under leaf sheath</li> <li>• They suck the juice from the cane and reduces the vigour of the plant</li> <li>• Sooty moulds develops giving blackish appearance to the canes</li> </ul> | <ul style="list-style-type: none"> <li>• Stripping of cane leaves</li> <li>• Need based spray of malathion or diazinon</li> </ul>                                                                                                                                                                                                                                                                                                                                            |

|                                            |                         |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pyrilla, <i>Pyrilla perpusilla</i>         | Lophopidae : Hemiptera  | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap</li> <li>• Plants infested loose vigour, become shrunken and quality of juice is affected</li> <li>• Canes dry up and die under severe attack</li> <li>• The honeydew secretion leads to development of sooty mould</li> </ul> | <ul style="list-style-type: none"> <li>• Release of parasitoid, <i>Epiricania melanoleuca</i> @ 4000 - 5000 cocoons or 4 - 5 lakh eggs / ha</li> <li>• Burning of trash helps in destroying unhatched egg masses and over-wintering nymphs</li> <li>• Need based spray of endosulfan or malathion</li> </ul> |
| Woolly aphid, <i>Ceratovacuna lanigera</i> | Aphididae : Hemiptera   | <ul style="list-style-type: none"> <li>• Nymphs and adults congregate in groups and weakens the cane and leaves turn into yellow colour because of sucking sap by aphids</li> </ul>                                                                                                                | <ul style="list-style-type: none"> <li>• Setting of yellow sticky traps</li> <li>• Release of parasitoid, <i>Dipha aphidvora</i></li> <li>• Need based spray of monocrotophos or metasystox</li> </ul>                                                                                                       |
| Whitefly, <i>Aleurolobus barodensis</i>    | Aleyroridae : Hemiptera | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap from the leaves and turning them yellow</li> </ul>                                                                                                                                                                             | <ul style="list-style-type: none"> <li>• Setting of yellow sticky traps</li> <li>• Detrash lower leaves containing the puparia</li> <li>• Need based spray of imidacloprid or triazophos</li> </ul>                                                                                                          |

## 11.6 DAMAGE AND MANAGEMENT OF MAJOR PESTS OF TOBACCO

| Insect pest                                      | Family :<br>Order            | Damage symptoms                                                                                                                                                                                  | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------------------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tobacco caterpillar,<br><i>Spodoptera litura</i> | Noctuidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>• Caterpillars cut the young seedlings</li> <li>• They voraciously feed on the leaves</li> <li>• Skeletonization of leaves and defoliation</li> </ul>     | <ul style="list-style-type: none"> <li>• Deep ploughing to exposure pupae to high temperature and thus destroy them</li> <li>• Sowing of castor as trap crop</li> <li>• Manual collection and destruction of egg masses and caterpillars</li> <li>• Installation of pheromone traps @ 10/ha</li> <li>• Spray of <i>Sl</i>-NPV @250 LE/ha</li> <li>• Release parasitoids like <i>Trichogramma</i> spp. @ (50,000/acre), <i>Bracon</i> spp. and <i>Campoletis</i> spp.</li> </ul> |
| Capsule borer,<br><i>Helicoverpa armigera</i>    | Noctuidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>• The caterpillars bore the capsules and destroy the seeds</li> <li>• When the infestation is heavy they come down and feed on the leaves also</li> </ul> | <ul style="list-style-type: none"> <li>• Monitoring by pheromone traps / light traps</li> <li>• Growing chickpea as ovipositional trap crop</li> <li>• Topping in inflorescence</li> <li>• Spray of <i>Ha</i>-NPV @250 LE/ha</li> <li>• Spray of B.t.k. @1.5 kg/ha</li> <li>• Release parasitoids like <i>Trichogramma</i> spp. @ (50,000/acre), <i>Bracon</i> spp. and <i>Campoletis</i> spp.</li> </ul>                                                                       |
| Stem borer,<br><i>Scrobipalpa heliopa</i>        | Gelechiidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Larvae bore inside the stem and causes swelling</li> <li>• Stunting and unusual</li> </ul>                                                              | <ul style="list-style-type: none"> <li>• Affected seedlings should be removed and destroyed</li> <li>• After harvestings the affected plants should be</li> </ul>                                                                                                                                                                                                                                                                                                               |

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|---------------------------------------------------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                   |                         | branching of the seedlings                                                                                                                                                                                                                                      | <p>uprooted and burnt to prevent carry over to the next season</p> <ul style="list-style-type: none"> <li>• Need based spray of quinalphos</li> </ul>                                                                                                                                                                                                                                                          |
| Whitefly, <i>Bemisia tabaci</i>                   | Aleyrodidae : Hemiptera | <ul style="list-style-type: none"> <li>• Adults and nymphs suck sap and due to this leaves become wrinkled, curled and twisted</li> <li>• It transmits leaf curl disease</li> </ul>                                                                             | <ul style="list-style-type: none"> <li>• Remove and destruction of alternate weed host</li> <li>• Install yellow-sticky traps (20 cm × 15 cm size galvanized iron sheet) coated with castor oil @ 5 per acre</li> <li>• Need based spray of acephate and methyl demeton</li> </ul>                                                                                                                             |
| Aphid, <i>Myzus persicae</i>                      | Aphididae : Hemiptera   | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap from leaves and later in leaves become curled and crinkled</li> <li>• Growth of black sooty mould due to honey-dew secretion</li> <li>• Acts as vector of various viral diseases</li> </ul> | <ul style="list-style-type: none"> <li>• Installation of yellow sticky traps</li> <li>• Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i> or <i>Syrphus / Scymnus</i> sp.</li> <li>• Need based spray of monocrotophos or methyl demeton</li> </ul>                                                                                                                               |
| Cigarette beetle : <i>Lasioderma serricorne</i> F | Ptinidae : Coleoptera   | <ul style="list-style-type: none"> <li>• It is a major pest of stored tobacco</li> <li>• The larvae feed on the leaves making large galleries and turn the leaf into powder</li> <li>• Holes cut in the high-grade tobacco reduces its quality</li> </ul>       | <ul style="list-style-type: none"> <li>• Keep the godowns and surroundings clean by removing tobacco bits</li> <li>• Prevent entry of beetles into the godowns</li> <li>• Need based spray of malathion</li> <li>• Fumigate heavily infested tobacco with aluminium phosphate tablets @ 1 tablet/ 1 cu.m for 96 hours</li> <li>• Treat the tobacco with insect growth regulator methoprene @ 10 ppm</li> </ul> |

### 11.7 MANAGEMENT OF LOCUSTS

- Beating the adults with thorny sticks, brooms or can be swept together and buried underground in heaps
- Hoppers can be burnt with flame throwers when they are resting during the night on bushes
- Setting up of poison baits on the feeding grounds
- Dusting of lindane 2 per cent, on crops, trees and on the ground
- Aerial application of lindane (2%) on top of a flying swarm
- Spraying of lindane 20EC, on locusts on the ground
- Digging of trench around the oviposition area, so that the young nymphs on emerging drop into it and can be buried alive, filling the ditch with soil
- The trenches can be dug in front of the moving army of nymphs, driving them into trenches with brooms and then buried alive
- Use of biological control agents such as *Trox proceras* (beetle) and myna bird
- Spraying the crop with neem seed kernel extract (5%)

### 11.8 MANAGEMENT OF TERMITES

- Stubble of the previous crops and other dead decaying matter should be removed
- Use well rotten organic manure
- Deep ploughing before sowing and mulching of crops with mustard straws
- Use of relatively less susceptible varieties to termite attack
- Destruction of termite queen and mound removal
- Treatment of termite mounds with 0.5% chlorpyrifos
- Application of the entomo-pathogenic fungus *Metarhizium anisopliae* at the time planting
- Use of *Calotropis procera* leaves and seed kernels of *Azadirachta indica*
- Use of chlorpyrifos 10 G as a soil treatment
- Seed dressing with chlorpyrifos 20 EC @ 12.5 ml/kg seed
- Application of phorate 10 G at 1.00 kg a.i./ha in the furrows at the time of sowing
- Adults and larvae of the predator beetle, *Omphra pilosa* (Coleoptera : Carabidae) feed exclusively on all castes of Isoptera



- Use of natural enemies such as *Sycanus collaris* (Reduviidae : Hemiptera), *Cydnocoris gilvus* (Reduviidae : Heteroptera) *Tetraponera rufonigra* (Hymenoptera : Formicidae); *Rhinocoris marginatus* (Reduviidae: Hemiptera); and *Coranus soosai* (Reduviidae : Hemiptera)

## 11.9 MANAGEMENT OF RED HAIRY CATERPILLAR

- Deep ploughing during April - May utilizing the summer showers to expose the pupae of red hairy caterpillar to sunlight and predatory birds
- With the receipt of s-w monsoon showers during June-July, it is recommended to set the bonfires on community basis on the field bunds from 7-10p.m starting from the next day of the rainy day using trash or old tyres etc.,
- Set up the light traps to attract and kill the moths during June-August
- Raise cowpea as trap crop around groundnut as the young larva prefers to feed on cowpea rather than groundnut
- Grow intercrops like castor or red gram at 1:11 ratio
- Form a deep furrow trench around the field and dust with 2% methyl parathion or 5% carbaryl to avoid the migration of larva from one field to the other
- Collection and destruction of egg masses and just emerged larva
- Place the vegetative traps like jatropha or calotropis in and around groundnut fields to attract and kill
- Spray neem oil @ 5 ml / lt water along with suitable surfactant like nirma powder 1g/lt or NSKE 5 % to suppress the eggs and just emerged larva
- Spray AaNPV @ 200 LE / acre at third instar stage
- If the damage exceeds ETL (25 % defoliation) spray quinalphos 2ml or chlorpyrifos 2.5ml per litre water

## 11.10 MANAGEMENT OF CUTWORMS

- Hand picking and destruction of caterpillars
- Digging of holes all over the fields so that the caterpillars fall into the holes and being cannibalistic kill each other
- Heavy irrigation or flooding kills the caterpillars by asphyxiation
- Provision of heaps of grasses so that the caterpillars congregate under heaps. Burning of heaps along with the caterpillars

- Application of lindane 2 per cent dust @ 125 kg per ha before planting the crop
- Setting of light traps to capture and killing of adults
- Drenching the soil around the plant and the ridges with chlorpyrifos 20EC @ 2.5 litres in 1000 litres of water per ha.

### 11.11 MANAGEMENT OF WHITE GRUB

- Field should be ploughed from the end of April to middle of May
- Mechanical control by large scale collection and destruction of adults at the time of their mass emergence
- Use of light traps and synthetic pheromone traps for monitoring
- Seed treatment with chlorpyrifos 20 EC or quinalphos 25 EC at 25 ml/kg
- Early sowing (pre-monsoon, irrigated) of crops should be done to allow roots to get established
- Pre sowing soil treatment with phorate 10 G at 25 kg /ha or quinalphos 5 G at 30 kg/ha
- Pheromone dispenser to be placed (2-3/tree) on the host tree in the evening continuously for three evenings for mass trapping of beetles
- Spray 0.05 % monocrotophos on one host tree from a group of host trees within the radius of 20 m.



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| UNIT |
| 12   |

## Pests of Horticultural Crops and their Management

### 12.1 DAMAGE AND MANAGEMENT OF MAJOR INSECT PESTS OF VEGETABLE CROPS

#### 1. Damage and management of major insect pests of Brinjal

| Insect pest                                                  | Family :<br>Order             | Damage symptoms                                                                                                                                                                                                                     | Specific management practices                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Spotted beetle,<br><i>Henosepilachna vigintioctopunctata</i> | Coccinellidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Grubs and adults feed on the upper surface of the leaves</li> <li>Skeletonization of leaves and lace like appearance</li> <li>Infested leaves dry up and fall</li> </ul>                     | <ul style="list-style-type: none"> <li>Collection and destruction of egg masses and skeletonised leaves with adults and grubs</li> <li>Hand picking of grubs and collection of beetles by hand nets</li> <li>Need based spray of carbaryl or malathion</li> </ul>                                                                                                              |
| Shoot and fruit borer, <i>Leucinodes orbonalis</i>           | Pyraustidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>Larva bores into tender shoots resulting in drying of tip</li> <li>It bores into developing fruits and bore hole plugged with excreta</li> <li>Damaged fruits unfit for marketing</li> </ul> | <ul style="list-style-type: none"> <li>Cultivation of resistant varieties such as Pusa purple round and Punjab Neelam</li> <li>Installation of pheromone traps for monitoring and mass trapping</li> <li>Removing and destroying affected shoots and fruits</li> <li>Avoid continuous cropping of brinjal</li> <li>Need based application of indoxacarb or carbaryl</li> </ul> |
| Stem borer, <i>Euzophera perticella</i>                      | Pyralidae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>Caterpillars bores into stem, attacked plants wither and wilt</li> </ul>                                                                                                                     | <ul style="list-style-type: none"> <li>Avoid ratooning of brinjal</li> <li>Uprooting and burning of infected plants</li> </ul>                                                                                                                                                                                                                                                 |

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|------------------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                |                         | <ul style="list-style-type: none"> <li>Growth is stunted and fruiting capacity is adversely affected</li> </ul>                                                                                 | <ul style="list-style-type: none"> <li>Need based spray of malathion or endosulfan</li> </ul>                                                                                                                                     |
| Lace wing bug,<br><i>Urantius hystricellus</i> | Tingidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from upper surface of leaves and cause yellowing of leaves in patches</li> <li>Circular discolored areas on leaves</li> </ul> | <ul style="list-style-type: none"> <li>Destruction of infested plants</li> <li>Release of lady beetle larvae and adults, spiders, and shield - shaped soldier bugs</li> <li>Need based spray of diazinon or dimethoate</li> </ul> |

## 2. Damage and management of major insect pests of Tomato

| Insect pest                                      | Family :<br>Order            | Damage symptoms                                                                                                                        | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fruit borer,<br><i>Helicoverpa armigera</i>      | Noctuidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>Caterpillars in the initial stages feed on the leaves and later bore into the fruits</li> </ul> | <ul style="list-style-type: none"> <li>Grow resistant variety, Avinash - 2</li> <li>Growing of African marigold as trap crop</li> <li>Use of pheromone traps (4 traps/acre) for monitoring</li> <li>Setting of light traps and bird perches @ 10 / acre</li> <li>Spray of <i>Ha</i> - NPV @ 250 LE / ha</li> <li>Spray of B.t.k @ 1.5 kg/ha</li> <li>Release parasitoids like <i>Trichogramma</i> spp. @ (50,000 / acre), <i>Bracon</i> spp. and <i>Campoletis</i> spp.</li> </ul> |
| Serpentine leaf miner, <i>Liriomyza trifolii</i> | Agromyzidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>Larvae mines into the leaves and in cases of severe damage leaves dry up</li> </ul>             | <ul style="list-style-type: none"> <li>Destruction of affected plants and parts</li> <li>Spray of neem seed kernel extract</li> </ul>                                                                                                                                                                                                                                                                                                                                              |

### 3. Damage and management of major insect pests of Potato

| Insect pest                                            | Family :<br>Order             | Damage symptoms                                                                                                                                                                                      | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Potato tuber moth,<br><i>Phthorimaea operculella</i>   | Gelechiidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>Mines on leaves and bore holes on tender shoot and tubers</li> </ul>                                                                                          | <ul style="list-style-type: none"> <li>Use of pest free seed material</li> <li>Earthing up the tuber crop</li> <li>Removing and destruction of infested tubers</li> <li>Installation of pheromone traps @10/ha for monitoring</li> <li>Release of <i>Bracon gelichiae</i>, <i>Copidosoma koehleri</i> and egg larval parasitoid. <i>Chelonus blackburni</i></li> <li>Need based spray of malathion</li> </ul> |
| Potato black cut worm, <i>Agrotis ipsilon</i>          | Noctuidae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>Caterpillar feed on young leaves and also cut tender stems at ground level</li> </ul>                                                                         | <ul style="list-style-type: none"> <li>Deep summer ploughing</li> <li>Collection and destruction of caterpillar</li> <li>Setting up of light traps to trap the adults</li> <li>Need based spray of carbaryl</li> </ul>                                                                                                                                                                                        |
| Hadda beetle,<br><i>Henosepilachna vigntiopunctata</i> | Coccinellidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Grubs and adults scrape epidermis of leaves on upper surface and produce characteristic streaks</li> <li>Severely affected leaves dry and fall off</li> </ul> | <ul style="list-style-type: none"> <li>Collection and destruction of egg masses and infested leaves with adults and grubs</li> <li>Hand picking of grubs and collection of beetles by hand nets</li> <li>Need based spray of carbaryl or malathion</li> </ul>                                                                                                                                                 |

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|----------------------------------------|--------------------------|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Potato aphid,<br><i>Myzus persicae</i> | Aphididae :<br>Hemiptera | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from leaves</li> </ul> | <ul style="list-style-type: none"> <li>Intercropping with cowpea</li> <li>Installation of yellow sticky traps</li> <li>Release of predators such as <i>Chrysoperla carnea</i> or <i>Coccinella septempunctata</i> or <i>Syrphus</i> / <i>Scymnus</i> sp.</li> <li>Need based spray of monocrotophos or methyl demeton</li> </ul> |
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#### 4. Damage and management of major insect pests of Okra

| Insect pest                                     | Family :<br>Order           | Damage symptoms                                                                                                                                                                                                                                                                                                           | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fruit borer, <i>Earias vittella</i>             | Noctuidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>Larva bores into terminal shoots of young plants leading death of the shoots and subsequent development of side shoots and branches</li> <li>Larva bores into the flower buds and fruits and shedding of infected fruits</li> <li>Entrance hole is plugged with excreta</li> </ul> | <ul style="list-style-type: none"> <li>Growing of cotton as trap crop</li> <li>Deep ploughing to expose resting pupae</li> <li>Avoid cotton fields for bhendi cultivation</li> <li>Avoid monocropping of bhendi year after year</li> <li>Release egg parasitoid <i>Trichogramma chilonis</i>, <i>T. brasiliensis</i>, and larval parasitoids <i>Chelonus blackburni</i> or <i>Bracon brevicornis</i> or <i>Apanteles</i> sp. at 35 to 70 days</li> </ul> |
| Leaf hopper, <i>Amrasca biguttata biguttata</i> | Cicadellidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>The damage caused due to sucking of sap by hoppers lead to curling and crinkling of leaves</li> </ul>                                                                                                                                                                              | <ul style="list-style-type: none"> <li>Growing of tolerant varieties</li> <li>Release of predators such as Coccinellids or <i>Chrysoperla</i> sp.</li> <li>Seed treatment with imidacloprid</li> <li>Need spray of imidacloprid or dimethoate</li> </ul>                                                                                                                                                                                                 |

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|---------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Whitefly, <i>Bemisia tabaci</i> | Aleyrodidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>• Nymphs and adults suck the sap from the under surface of the leaves and excrete honeydew</li> <li>• Leaves appear sickly and get coated with sooty mold</li> <li>• Stunted plant growth, shedding of fruits</li> <li>• It transmits yellow vein mosaic virus</li> </ul> | <ul style="list-style-type: none"> <li>• Setting of yellow / sticky traps, which are coated with grease / sticky oily materials</li> <li>• Growing of tolerant varieties</li> <li>• Avoid using of synthetic pyrethroids</li> <li>• Spray trizophos (2.5 ml/l) or prophenophos (2 ml/l).</li> </ul> |
|---------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### 5. Damage and management of major pests of Chilli

| Insect pest                              | Family :<br>Order          | Damage symptoms                                                                                                                              | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fruit borer, <i>Helicoverpa armigera</i> | Noctuidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars bore into the fruit and feeds</li> </ul>                                               | <ul style="list-style-type: none"> <li>• Growing of African marigold as trap crop</li> <li>• Use of pheromone traps (10 traps/ha)</li> <li>• Setting of light traps and bird perches @ 10/acre</li> <li>• Use of <i>Ha</i>-NPV @250LE/ha</li> <li>• Use of B.t.k @1.5 kg/ha</li> <li>• Release of parasitoids such as <i>Trichogramma</i> spp. @ (50,000/acre), <i>Bracon</i> spp. and <i>Campoletis</i> spp.</li> </ul> |
| Fruit borer, <i>Spodoptera litura</i>    | Noctuidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars initially cause defoliation and once fruits are formed bore into the fruits</li> </ul> | <ul style="list-style-type: none"> <li>• Growing of castor as trap crop</li> <li>• Deep ploughing to exposure pupae to high temperature and thus destroy them</li> </ul>                                                                                                                                                                                                                                                 |

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|                                               |                             |                                                                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>• Manual collection and destruction of egg masses and caterpillars</li> <li>• Installation of pheromone traps @ 10/ha</li> <li>• Spray of <i>Sl-NPV</i> @250 LE/ha</li> <li>• Release parasitoids like <i>Trichogramma</i> spp. @ (50,000/acre), <i>Bracon</i> spp. and <i>Campolestis</i> spp.</li> </ul> |
| Chilli thrips, <i>Scirtothrips dorsalis</i>   | Thripidae :<br>Thysanoptera | <ul style="list-style-type: none"> <li>• Adults and nymphs lacerate the leaf tissue and suck the sap</li> <li>• Upward curling of leaves</li> <li>• Attacked plants are stunted, leaves drop, fresh buds become brittle and drop down</li> </ul> | <ul style="list-style-type: none"> <li>• Destruction of affected plants</li> <li>• Release of predators such as <i>Chrysoperla</i> or coccinellid beetles</li> <li>• Need based spray of acephate or fipronil</li> </ul>                                                                                                                          |
| Chilli mite, <i>Polyphagotarsonemus latus</i> | Tarsonemidae :<br>Acarina   | <ul style="list-style-type: none"> <li>• Nymphs and adults feed exclusively on lower surface of leaves</li> <li>• Leaf curls down ward along the margins of the leaf and attain an inverted boat shape</li> </ul>                                | <ul style="list-style-type: none"> <li>• Destruction of affected plants</li> <li>• Release of predators such as <i>Chrysoperla</i> or Coccinellid beetles</li> <li>• Need based spray of dicofol or sulphur</li> </ul>                                                                                                                            |



## 6. Damage and management of major insect pests of Cruciferous vegetables

| Insect pest                                   | Family :<br>Order            | Damage symptoms                                                                                                                                                                                   | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----------------------------------------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Diamond back moth, <i>Plutella xylostella</i> | Plutellidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Mining and skeletonization of cabbage leaves</li> <li>• Larvae also feeds on cabbage</li> </ul>                                                          | <ul style="list-style-type: none"> <li>• Growing bold seeded mustard as trap crop</li> <li>• Installation of pheromone traps for monitoring and mass trapping</li> <li>• Release of parasitoids such as <i>Apanteles plutellae</i> and <i>Diadegma semiclausum</i></li> <li>• Remove and destroy all the remnants and stubbles after the harvest of the crop</li> <li>• Need based spray of quinalphos or fenvalerate</li> </ul> |
| Leaf webber, <i>Crocidolomia binotalis</i>    | Pyalidae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>• Caterpillar webs the green leaves with silken thread and skeletonizes the webbed leaves</li> </ul>                                                       | <ul style="list-style-type: none"> <li>• Hand picking and mechanical destruction of caterpillars</li> <li>• Release of parasitoid, <i>Apanteles glomeratus</i></li> <li>• Need based spray of malathion or dichlorvos</li> </ul>                                                                                                                                                                                                 |
| Cabbage borer, <i>Hellula undalis</i>         | Pyalidae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>• Young larvae mine into the leaves and feed on leaf surface</li> <li>• Larvae bore into stem, stalk and cabbage and consumes its inner content</li> </ul> | <ul style="list-style-type: none"> <li>• Collection and mechanical destruction of caterpillars</li> <li>• Installation of pheromone traps for monitoring</li> <li>• Need based spray of endosulfan or carbaryl</li> </ul>                                                                                                                                                                                                        |
| Cabbage butterfly, <i>Pieris brassicae</i>    | Pieridae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>• Caterpillars scrape the leaves and eat up leaves leaving only main veins</li> <li>• Defoliation of the plant</li> </ul>                                  | <ul style="list-style-type: none"> <li>• Collection and mechanical destruction of caterpillars</li> <li>• Release of parasitoid, <i>Apanteles glomeratus</i></li> <li>• Need based spray of endosulfan or malathion</li> </ul>                                                                                                                                                                                                   |

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|                                                                         |                               |                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------------------|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cabbage aphid,<br><i>Brevicoryne brassicae</i><br><i>Myzus persicae</i> | Aphididae :<br>Hemiptera      | <ul style="list-style-type: none"> <li>The adults and young ones suck sap resulting in retardation of growth and development of sooty mould</li> </ul>  | <ul style="list-style-type: none"> <li>Setting of yellow sticky traps</li> <li>Grow resistant cabbage varieties such as All season and Red drum head</li> <li>Release predator <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i> or <i>Syrphus</i> / <i>Scymnus</i> sp.</li> <li>Need based spray of dimethoate 30 EC or methyl demeton 25 EC</li> </ul> |
| Flea beetle,<br><i>Phyllotreta cruciferae</i>                           | Chrysomelidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Grubs and adults damage the leaves and cut it</li> <li>Attacked plants emit decaying odour</li> </ul>            | <ul style="list-style-type: none"> <li>Need based spray of carbaryl</li> </ul>                                                                                                                                                                                                                                                                                       |
| Painted bug,<br><i>Bagrada cruciferarum</i>                             | Pentatomidae :<br>Hemiptera   | <ul style="list-style-type: none"> <li>Both nymphs and adults suck sap from leaves</li> <li>Due to feeding the vigour of the crop is reduced</li> </ul> | <ul style="list-style-type: none"> <li>Clean cultivation</li> <li>Need based spray of endosulfan or malathion</li> </ul>                                                                                                                                                                                                                                             |

## 7. Damage and management of major insect pests of Cucurbitaceous vegetables

| Insect pest                                        | Family :<br>Order             | Damage symptoms                                                                                                                                                                               | Specific management practices                                                                                                                                                               |
|----------------------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Red pumpkin beetle, <i>Aulacophora foveicollis</i> | Chrysomelidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Irregular holes on the cucurbit leaves</li> <li>Grubs bore into the roots and underground stems</li> </ul>                                             | <ul style="list-style-type: none"> <li>Avoid early sowing</li> <li>Deep ploughing to kill the grubs</li> <li>Need based spray of carbaryl</li> </ul>                                        |
| Cucurbit fruit flies, <i>Bactrocera cucurbitae</i> | Tephritidae :<br>Diptera      | <ul style="list-style-type: none"> <li>Maggots feed on the pulp and seeds inside</li> <li>The affected fruits may fall prematurely</li> <li>Infested fruits become soft and rotten</li> </ul> | <ul style="list-style-type: none"> <li>Deep ploughing for killing of pupae</li> <li>Removal and destruction of infested fruits</li> <li>Setting of baits mixed with insecticides</li> </ul> |
| Semilooper, <i>Plusia orichalcea</i>               | Noctuidae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>Damage cucurbits by biting holes on leaves</li> </ul>                                                                                                  | <ul style="list-style-type: none"> <li>Clean cultivation</li> <li>Collection and destruction of caterpillars</li> <li>Need based spray of endosulfan or carbaryl</li> </ul>                 |

## 12.2 DAMAGE AND MANAGEMENT OF MAJOR INSECT PESTS OF FRUIT CROPS

### 1. Damage and management of major insect pests of Mango

| Insect pest                                                             | Family :<br>Order            | Damage symptoms                                                                                                                                                                                                      | Specific management practices                                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mango hoppers,<br><i>Idioscopus</i> spp.,<br><i>Amritodus atkinsoni</i> | Cicadellidae :<br>Hemiptera  | <ul style="list-style-type: none"> <li>Drying of inflorescence with large scale withering and shedding of mango flowers</li> <li>Development of sooty mould due to honey dew secretions</li> </ul>                   | <ul style="list-style-type: none"> <li>Avoid high density planting</li> <li>Avoid frequent irrigation and split doses of nitrogen fertilizers</li> <li>Avoid water logging</li> <li>Need based spray of carbaryl or malathion</li> </ul>                                          |
| Mango stem borer,<br><i>Batocera rufomaculata</i>                       | Cerambycidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Bore holes on mango stem with protrusion of branches</li> </ul>                                                                                                               | <ul style="list-style-type: none"> <li>Cut and destroy the infested branches</li> <li>Injecting methyl parathion into the bore holes and plug with mud</li> </ul>                                                                                                                 |
| Mango mealy bug,<br><i>Drosicha mangiferae</i>                          | Margarodidae :<br>Hemiptera  | <ul style="list-style-type: none"> <li>Large number of mealy bugs are found on stalks and fruits where they affect the quality of fruit</li> <li>Nymphs and adults suck plant juice and the leaves dry up</li> </ul> | <ul style="list-style-type: none"> <li>Banding of trees with sticky alkathene or plastic sheets</li> <li>Removal of weeds</li> <li>Deep summer ploughing</li> <li>Release of predators, <i>Cryptolaemus montrouzieri</i></li> <li>Need based spray of methyl parathion</li> </ul> |
| Mango fruit fly,<br><i>Bactrocera dorsalis</i>                          | Tephritidae :<br>Diptera     | <ul style="list-style-type: none"> <li>Maggots feed on the pulp of the fruit and the affected portion rot and the fruit drops off</li> </ul>                                                                         | <ul style="list-style-type: none"> <li>Deep ploughing for killing of pupae</li> <li>Removal and destruction of infested fruits</li> <li>Setting up of sex lure trap with methyl eugenol</li> </ul>                                                                                |

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|--------------------------------------------------------------------|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                    |                                       |                                                                                                                                                                                                                                                                                                                        | <p>to monitor the activity</p> <ul style="list-style-type: none"> <li>• Setting of baits with methyl eugenol + insecticide</li> </ul>                                                                                                                                                                                                                                                                                           |
| <p>Mango stone or nut weevil,<br/><i>Sternuchus mangiferae</i></p> | <p>Curculionidae :<br/>Coleoptera</p> | <ul style="list-style-type: none"> <li>• Monophagous pest of mango</li> <li>• 'T' shaped marking on marble sized mango fruits</li> <li>• Grubs tunnel through pulp, endocarp, and finally reach the cotyledon and feed on them</li> <li>• Germination is affected</li> <li>• Fruit dropping at marble stage</li> </ul> | <ul style="list-style-type: none"> <li>• Destroy fallen fruits</li> <li>• Depose off refuse and debris</li> <li>• Cleanliness and destruction of the weevils on the bark</li> <li>• Washing the infested bark with kerosene emulsion</li> <li>• Drenching the tree trunk upto a height of 4m with carbaryl @0.2%</li> <li>• Need based spray of deltamethrin @0.002% (1 ml/l of water) after six weeks of fruit set</li> </ul>  |
| <p>Red ant,<br/><i>Oecophylla smaragdina</i></p>                   | <p>Formicidae :<br/>Hymenoptera</p>   | <ul style="list-style-type: none"> <li>• Webbing mango leaves with petiole intact</li> <li>• Being ferocious cause nuisance to workers</li> </ul>                                                                                                                                                                      | <ul style="list-style-type: none"> <li>• Nests should be removed and destroyed mechanically or by spraying contact insecticides, after disturbing the nest</li> </ul>                                                                                                                                                                                                                                                           |
| <p>Oriental fruit fly,<br/><i>Bactrocera dorsalis</i></p>          | <p>Tephritidae :<br/>Diptera</p>      | <ul style="list-style-type: none"> <li>• Both adults and nymphs cause damage and fruit become unmarketable</li> <li>• Adults feed on the exudation of ripe fruits</li> <li>• The maggots destroy the pulp and emit foul smell</li> <li>• Fruit develop brown rotten patches and fall to the ground</li> </ul>          | <ul style="list-style-type: none"> <li>• Early harvesting of mature fruits</li> <li>• Collection and disposal of the fallen infested fruits</li> <li>• Monitoring by using methyl eugenol traps</li> <li>• Under - sized fruits left on the tree should be picked and destroyed</li> <li>• Spray of diesel-oil emulsion for the destruction of adult flies congregating in the night under the leaves of fruit trees</li> </ul> |

## 2. Damage and management of major insect pests of Citrus

| Insect pest                                                                              | Family :<br>Order               | Damage symptoms                                                                                                                                                                                                               | Specific management practices                                                                                                                                                                                                                                                                                                                           |
|------------------------------------------------------------------------------------------|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Citrus fruit sucking moth, <i>Othreis fulonica</i> , <i>O.materna</i> , <i>O.ancilla</i> | Noctuidae :<br>Lepidoptera      | <ul style="list-style-type: none"> <li>Adults suck the juice from ripening fruits resulting in dropping</li> <li>Shedding of fruits with feeding punctures</li> </ul>                                                         | <ul style="list-style-type: none"> <li>Destruction of weed hosts</li> <li>Smoking below the trees to scare away the moths</li> <li>Bagging of fruits with polythene or paper cover to avoid damage by adults</li> <li>Destruction of the fallen and decaying fruits</li> <li>Setting of light and placing of water mixed with kerosene below</li> </ul> |
| Lemon butterfly, <i>Papilio demoleus</i>                                                 | Papilionidae :<br>Lepidoptera   | <ul style="list-style-type: none"> <li>The caterpillar voraciously feeds on tender leaves and leaving only the mid-ribs</li> <li>In the case of severe infestation the entire tree gets defoliated</li> </ul>                 | <ul style="list-style-type: none"> <li>Hand picking of various stages of the pest and destruction of the same</li> <li>Use of natural enemies such as, <i>Trichogramma evanescens</i> and <i>Telenomus</i> sp on eggs, <i>Brachymeria</i> sp on larvae and <i>Pterolus</i> sp. on pupae</li> <li>Need based spray of quinalphos or carbaryl</li> </ul>  |
| Citrus leaf-miner, <i>Phyllocnistis citrella</i>                                         | Gracillariidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>Tender leaves are attacked and larvae feed on the epidermis, making silver-coloured serpentine mines on the lower surface</li> <li>The leaves become distorted and crinkled</li> </ul> | <ul style="list-style-type: none"> <li>Spray of neem seed kernel extract is also useful</li> <li>Need based spray of monocrotophos or dimethoate</li> </ul>                                                                                                                                                                                             |
| Citrus psylla, <i>Diaphorina citri</i>                                                   | Psyllidae :<br>Hemiptera        | <ul style="list-style-type: none"> <li>Both nymphs and adults suck sap from the plants</li> </ul>                                                                                                                             | <ul style="list-style-type: none"> <li>Destruction of infested branches</li> </ul>                                                                                                                                                                                                                                                                      |

|                                                                                |                               |                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                |                               | <ul style="list-style-type: none"> <li>• Nymphs inject toxins into the plant, as a result the affected parts and adjacent branches dry and die away</li> <li>• Excrete honeydew resulting in growth of sooty moulds</li> <li>• Psylla transmits the “Greening” virus</li> </ul>                                                                 | <ul style="list-style-type: none"> <li>• Use of predators such as <i>Coccinella septempunctata</i>, and <i>Chrysoperla</i> sp.</li> <li>• Need based spray of monocrotophos</li> </ul>                                                                                                                  |
| Citrus aphid,<br><i>Toxoptera citricidi</i>                                    | Aphididae :<br>Hemiptera      | <ul style="list-style-type: none"> <li>• Adults and nymphs infest tender shoots and leaves</li> <li>• They suck the sap of the leaves, causing wilting of the foliage and flower drop</li> <li>• The infested leaves are cup shaped and crinkled</li> <li>• Growth of the plants is hindered</li> </ul>                                         | <ul style="list-style-type: none"> <li>• Setting of yellow sticky traps</li> <li>• Release of predators such as <i>Chrysoperla carnea</i> or <i>Coccinella septempunctata</i> or <i>Syrphus</i> / <i>Scymnus</i> sp.</li> <li>• Need based spray of dimethoate 30 EC or methyl demeton 25 EC</li> </ul> |
| Citrus shoot and bark caterpillar,<br><i>Indarbela tetraonis</i>               | Metarbelidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• The larvae feeds on the bark of the tree and webs galleries of wooden particles, silk and excreta, which are plastered on tree trunks</li> </ul>                                                                                                                                                       | <ul style="list-style-type: none"> <li>• Destruction of alternate hosts</li> <li>• Killing the larva by poking a wire down the tunnel or pouring kerosene or dichlorvos into the tunnel and sealing it with clay</li> </ul>                                                                             |
| Citrus blackfly,<br><i>Aleurocanthus woglumi</i> ,<br><i>Dialeurodus citri</i> | Aleurodiade :<br>Homoptera    | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap resulting in leaf curl</li> <li>• Leaves fall off immaturely</li> <li>• Secretes honeydew in large amounts which spread over the leaf surface giving rise to black fungus</li> <li>• Affected trees produce only a few blossoms which develop into inspid fruits</li> </ul> | <ul style="list-style-type: none"> <li>• Spraying on the lower surface of the leaves</li> <li>• The entire plant canopy should be drenched with insecticidal solution</li> <li>• Release of predators such as <i>Brumus</i> sp., <i>Scymnus</i> sp., and <i>Chrysoperla</i> sp.</li> </ul>              |

### 3. Damage and management of major insect pests of Guava

| Insect pest                                       | Family :<br>Order          | Damage symptoms                                                                                                                                                                | Specific management practices                                                                                                                                                                                                                                                                               |
|---------------------------------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Guava tea mosquito bug, <i>Helopeltis antonii</i> | Miridae :<br>Hemiptera     | <ul style="list-style-type: none"> <li>• Corky out growth or scab formation</li> <li>• Drying of shoots, inflorescence and dropping of the flowers and young fruits</li> </ul> | <ul style="list-style-type: none"> <li>• Destruction of infested plants</li> <li>• Need based spray of carbaryl or endosulfan</li> </ul>                                                                                                                                                                    |
| Spiraling whitefly, <i>Aleurodicus dispersus</i>  | Aleyrodidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>• Yellowing of leaves and development of sooty mould</li> </ul>                                                                         | <ul style="list-style-type: none"> <li>• Clean cultivation</li> <li>• Removal of weeds and other alternate host plants</li> <li>• Release of predators such as <i>Encarsia gudeloupae</i>, <i>Chrysoperla</i> and Coccinellid beetles</li> <li>• Need based spray of metasystox or monocrotophos</li> </ul> |
| Scale Insect, <i>Pulvinaria psidii</i>            | Coccidae :<br>Hemiptera    | <ul style="list-style-type: none"> <li>• Females and nymphs suck sap from leaves</li> <li>• Leaves fall off and twigs dry up under severe attack</li> </ul>                    | <ul style="list-style-type: none"> <li>• Pruning and destruction of infested shoots</li> <li>• Release of predator, <i>Cryptolaemus montrouzieri</i></li> <li>• Need based spray of diazinon or monocrotophos</li> </ul>                                                                                    |
| Fruit borer, <i>Conoganthes punctiferalis</i>     | Pyralidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars feed on the fruits and dropping of fruits</li> </ul>                                                                     | <ul style="list-style-type: none"> <li>• Infested fruits should be collected and destroyed</li> <li>• Need based spray of carbaryl</li> </ul>                                                                                                                                                               |



#### 4. Damage and management of major insect pests of Banana

| Insect pest                                                  | Family :<br>Order             | Damage symptoms                                                                                                                                                                                                                                                                                 | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rhizome weevil,<br><i>Cosmopolites sordidus</i>              | Curculionidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>• Grubs bore into the pseudostem and rhizome and make tunnels by feeding and presence of bore holes</li> <li>• Adults bore into the suckers, the central shoots gets killed</li> <li>• Plants show premature withering and suckers get killed</li> </ul> | <ul style="list-style-type: none"> <li>• Drenching of soil with chlorpyrifos before planting</li> <li>• Planting of healthy suckers</li> <li>• Clean cultivation</li> <li>• Removal of pseudostems below ground level</li> <li>• Trimming the rhizome</li> <li>• Trapping of adults using yellow traps</li> <li>• Use of carbofuran or phorate granules for soil incorporation at time of planting</li> </ul> |
| Banana rusty thrips,<br><i>Chaetonaphothrips signipennis</i> | Thripidae :<br>Thysanoptera   | <ul style="list-style-type: none"> <li>• Red discolouration between individual fingers</li> <li>• The skin becomes reddish brown, roughened and dull in appearance, superficial cracks appear in discoloured skin</li> </ul>                                                                    | <ul style="list-style-type: none"> <li>• Using only clean corms</li> <li>• Release of predators such as <i>Chrysoperla</i> and Coccinellid beetles</li> <li>• Need based spray of metasystox</li> </ul>                                                                                                                                                                                                       |
| Banana aphid,<br><i>Pentalonia nigronervosa</i>              | Aphididae :<br>Hemiptera      | <ul style="list-style-type: none"> <li>• Nymphs and adults suck sap from leaves and mainly does indirect damage as vector of bunchy top of banana</li> </ul>                                                                                                                                    | <ul style="list-style-type: none"> <li>• The injection of monocrotophos into the pseudostem</li> <li>• Applying granules at the time of planting to the rhizome or base of sucker</li> <li>• Need based spray of 0.03% metasystox or dimethoate</li> </ul>                                                                                                                                                    |

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|----------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Banana stem borer,<br><i>Odoiporus longicollis</i> | Curculionidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>• Grubs bore into the rhizome and make tunnels within it</li> <li>• Adults tunnel with in the stem, feed on the internal tissues as a result the internal shoot is killed</li> <li>• Infested plants show premature withering and fruits become undersized</li> </ul> | <ul style="list-style-type: none"> <li>• Uproot and burn the infested plants</li> <li>• Dipping of suckers in lindane solution to kill the eggs</li> <li>• Need based spray of carbaryl or endosulfan</li> </ul> |
|----------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### 5. Damage and management of major insect pests of Grapes

| Insect pest                                                                          | Family :<br>Order             | Damage symptoms                                                                                                                                                                    | Specific management practices                                                                                                                                                                                                                                        |
|--------------------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Grapevine flea beetle,<br><i>Scelodonta strigicollis</i>                             | Chrysomelidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>• Grubs feed on roots and adults feed on tender leaves and buds resulting in shot holes</li> <li>• Effected buds dry up and fall</li> </ul> | <ul style="list-style-type: none"> <li>• Removal of loose bark at time of pruning prevents egg laying by flea beetle</li> <li>• Collection and destruction of adult beetles</li> <li>• Need based spray of carbaryl or chlorpyrifos</li> </ul>                       |
| Grapevine mealy bug,<br><i>Maconellicoccus hirsutus</i> ,<br><i>Ferrisia virgata</i> | Pseudococcidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>• Sticky, shriveled grapes</li> <li>• Berries with sooty mould</li> </ul>                                                                   | <ul style="list-style-type: none"> <li>• Destruction of affected parts</li> <li>• Removal of weeds and alternate hosts</li> <li>• Release of predators such as <i>Chrysoperla</i> and coccinellid beetles</li> <li>• Need based spray of methyl parathion</li> </ul> |
| Grapevine stem girdler, <i>Sthenias gresator</i>                                     | Cerambycidae :<br>Coleoptera  | <ul style="list-style-type: none"> <li>• Spiral cut on the grapevine stem (ringing the vine)</li> </ul>                                                                            | <ul style="list-style-type: none"> <li>• Cutting and burning of attacked branches below the girdling point</li> <li>• Hand collection and destruction of beetles</li> </ul>                                                                                          |

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|---------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Grapevine beetle,<br><i>Sinoxylon anale</i> | Bostrychidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Both adult and grubs cause damage by feeding inside the vine stem</li> <li>Adult beetle make circular hole and build longitudinal galleries with a number of exits</li> </ul> | <ul style="list-style-type: none"> <li>Swabbing the trunk with carbaryl</li> <li>Clean cultivation</li> <li>Removal of loose bark and careful pruning</li> <li>Destruction of infested parts</li> <li>Need based spray of monocrotophos or carbaryl</li> </ul> |
|---------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 6. Damage and management of major insect pests of Pomegranate

| Insect pest                                              | Family :<br>Order           | Damage symptoms                                                                                                                                                                                                | Specific management practices                                                                                                                                                                     |
|----------------------------------------------------------|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Anar butterfly / fruit borer, <i>Virachola isocrates</i> | Lycaenidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>Bore hole on pomegranate fruits surrounded by faecal material and feeds on inner content</li> <li>Infested fruits are attacked by bacteria and fungi and rot</li> </ul> | <ul style="list-style-type: none"> <li>Bagging of fruits with polythene cover</li> <li>Collection and destruction of fallen infested fruits</li> <li>Need based spray of monocrotophos</li> </ul> |

## 7. Damage and management of major insect pests of Apple, Pear, Peach and Plum

| Insect pest                                 | Family :<br>Order        | Damage symptoms                                                                                                                                    | Specific management practices                                                                                                                                                                                                  |
|---------------------------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Apple wooly aphid, <i>Eriosoma lanigera</i> | Aphididae :<br>Hemiptera | <ul style="list-style-type: none"> <li>Aphids suck sap from twigs and from the roots</li> <li>Ashy coat on apple stem with galled roots</li> </ul> | <ul style="list-style-type: none"> <li>Use of resistant root stocks such as Golden delicious and Northern Spy</li> <li>Release of parasitoid, <i>Aphelinus mali</i></li> <li>Selecting of healthy planting material</li> </ul> |

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|-------------------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                       |                              |                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>• Need based spray of diazinon or oxydemeton methyl</li> </ul>                                                                                                                                                                                                                                           |
| San Jose scale,<br><i>Quadraspidiotus perniciosus</i> | Diaspididae :<br>Hemiptera   | <ul style="list-style-type: none"> <li>• Nymphs and adult females suck sap from twigs branches and fruits</li> <li>• The infested region on bark turns into pink colour</li> <li>• Pink colour encrustation on apple fruits</li> </ul> | <ul style="list-style-type: none"> <li>• Infested pruned material should be collected and burnt</li> <li>• Augmentation and inoculative release of parasitoids, <i>Encarsia perniciosi</i> and <i>Aphytis</i> sp.</li> <li>• Need based spray of diazinon or oxydemeton methyl</li> </ul>                                                       |
| Apple stem borer,<br><i>Apriona cinerea</i>           | Cerambycidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>• Grubs by making a circular hole bores into the stem and in severe cases the branch dry and wilts</li> </ul>                                                                                   | <ul style="list-style-type: none"> <li>• Pruning and burning of infested shoots and branches</li> <li>• Injection of carbon disulphide or chloroform into the live holes</li> <li>• Placing of aluminium phosphide tablets inside the hole and then plugging with moist soil</li> <li>• Need based spray of dichlorvos or dimethoate</li> </ul> |
| Codling moth,<br><i>Cydia pomonella</i>               | Tortricidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Larvae burrow into the fruit and feed on the pulp</li> <li>• Infested fruits lose their shape and fall off prematurely</li> </ul>                                                             | <ul style="list-style-type: none"> <li>• Destruction of infested fruits</li> <li>• Need based spray of endosulfan or carbaryl</li> </ul>                                                                                                                                                                                                        |

### 12.3 DAMAGE AND MANAGEMENT OF MAJOR INSECT PESTS OF PLANTATION CROPS

#### 1. Damage and management of major pests of Coconut

| Insect pest                                         | Family :<br>Order             | Damage symptoms                                                                                                                                                                                                                                                                                                                                                                                     | Specific management practices                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-----------------------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Red palm weevil,<br><i>Rhychophorus ferrugineus</i> | Curculionidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Gummosis (oozing of brown liquid) and crown toppling in coconut</li> <li>Drying up of the young heart leaves or splitting of the petioles near the area of attack</li> </ul>                                                                                                                                                                                 | <ul style="list-style-type: none"> <li>Cutting and burning of the dead and dried palms</li> <li>Installation of pheromone traps for mass trapping</li> <li>Release of parasite, <i>Scotia erratica</i></li> <li>Root feeding with monocrotophos</li> </ul>                                                                                                                                                                                                                                                                                                           |
| Rhinoceros beetle,<br><i>Oryctes rhinoceros</i>     | Dynastidae :<br>Coleoptera    | <ul style="list-style-type: none"> <li>Beetle bores into central shoots, spathes and petioles, chews the tissues, ingests the juice and throws out dry fibrous part</li> <li>Attacked central shoot topples down and the tree is killed if the growing primordium is destroyed</li> <li>Leaves of partly damaged crowns when grow show characteristic 'V' shaped cuttings on the leaflet</li> </ul> | <ul style="list-style-type: none"> <li>Removal of potential breeding sites and treating with <i>Metarrhizium anisopliae</i></li> <li>Treat the manure pits with carbaryl dust</li> <li>Installation of pheromone traps for monitoring and mass trapping</li> <li>Setting of light traps</li> <li>Hook out beetles from crowns</li> <li>Release of natural enemy, <i>Platymeris laevicollis</i></li> <li>Spray of <i>Oryctes</i> non occluded virus</li> <li>Setting up of poison bait made out of rotting mustard, castor cake, toddy or dung and lindane</li> </ul> |

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|-----------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Black headed caterpillar, <i>Opisina arenosella</i> | Xylorectidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Scrapes the green matter on lower surface of fronds</li> <li>• Dried leaflets with gallery of silk and frass and lives under it</li> <li>• Burnt up appearance from a distance</li> <li>• Bearing capacity of the tree and fruit size is reduced</li> </ul> | <ul style="list-style-type: none"> <li>• Clipping and burning of infested leaflets</li> <li>• Root administration of monocrotophos</li> <li>• Inundative release of parasitoids, <i>Goniozus nephantidis</i> and <i>Bracon brevicornis</i> at 300 and 4500 per ha</li> <li>• Release of pupal parasitoid <i>Trichospilus pupivora</i>, and <i>Spoggosia bezziana</i></li> </ul> |
| Coconut slug caterpillar, <i>Contheyla rotunda</i>  | Cochilidiidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars feed gregariously on the leaves and cause severe defoliation</li> </ul>                                                                                                                                                                        | <ul style="list-style-type: none"> <li>• Collection and destruction of larvae</li> <li>• Root feeding with monocrotophos</li> </ul>                                                                                                                                                                                                                                             |
| Scale, <i>Aspidiotus destructor</i>                 | Diaspididae :<br>Hemiptera     | <ul style="list-style-type: none"> <li>• Nymphs feed on leaves and suck cell sap, congregate on green nuts and suck sap reducing the quality</li> <li>• Leaflets turn yellowish and in severe cases wither and dry</li> </ul>                                                                        | <ul style="list-style-type: none"> <li>• Collection and destruction of infested plants</li> <li>• Release of natural enemies such as coccinellid beetles and <i>Chrysoperla</i> sp.</li> <li>• Root administration of monocrotophos</li> </ul>                                                                                                                                  |
| Coconut mite, <i>Aceria guerreonis</i>              | Eriophyidae :<br>Acarina       | <ul style="list-style-type: none"> <li>• Discolouration on nuts and the market value of nuts is affected</li> </ul>                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>• Removing dried spathes, inflorescence parts, fallen nuts etc. and destroy them</li> <li>• Combination treatment containing neem formulation (5ml) with entomopathogenic fungus, <i>Hirsutella thompsonii</i> (5g) per tree</li> <li>• Need based spray of sulphur 80 % SP @ 6 grams / litre</li> </ul>                                 |

## 2. Damage and management of major insect pests of Coffee

| Insect pest                                       | Family :<br>Order            | Damage symptoms                                                                                                                                                                                  | Specific management practices                                                                                                                                                                                                                                                                                              |
|---------------------------------------------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Green bug / scale,<br><i>Coccus viridis</i>       | Coccidae :<br>Hemiptera      | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from leaves and shoots and vigour of plant is affected</li> <li>Discoloration and malformation of leaves and fruits</li> </ul> | <ul style="list-style-type: none"> <li>Field sanitation, uprooting of infested plants</li> <li>Use of effective biological control agents such as <i>Cryptolaemus montrouzieri</i> and <i>Chrysoperla carnea</i></li> <li>Use of <i>Verticillium lecanii</i></li> <li>Dusting of methyl parathion or dimethoate</li> </ul> |
| Berry borer,<br><i>Hypothenemus hampei</i>        | Scolytidae :<br>Coleoptera   | <ul style="list-style-type: none"> <li>The beetle bore into the berries and they become unfit for processing</li> </ul>                                                                          | <ul style="list-style-type: none"> <li>Collection and destruction of affected berries</li> <li>Release of natural enemies such as <i>Phymastichus coffea</i> and <i>Prorops nasuta</i></li> <li>Need based spray of quinalphos</li> </ul>                                                                                  |
| White stem borer,<br><i>Xylotrechus quadripes</i> | Cerambycidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Grub tunnels into stem and branches resulting in death of plant or wilting of branches and galleries are filled with frass</li> </ul>                     | <ul style="list-style-type: none"> <li>Removing and destroying of affected shoots</li> <li>Mass collection and killing the beetles</li> <li>Swabbing of main stem and thick primary branches with lindane emulsion</li> </ul>                                                                                              |
| Shot hole borer,<br><i>Xylosandrus compactus</i>  | Scolytidae :<br>Coleoptera   | <ul style="list-style-type: none"> <li>Grubs bore into twigs resulting in drying of the damaged branch</li> <li>Powdery material comes out from the damaged hole</li> </ul>                      | <ul style="list-style-type: none"> <li>Removing and destroying of affected shoots</li> <li>Need based spray of malathion or methyl parathion</li> </ul>                                                                                                                                                                    |

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|----------------------------------------------|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                              |                         | <ul style="list-style-type: none"> <li>• Wilting, defoliation and dieback of affected plants</li> </ul>                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                     |
| Coffee mealy bug,<br><i>Ferrisia virgata</i> | Coccidae :<br>Hemiptera | <ul style="list-style-type: none"> <li>• Nymphs and adults infests shoots and also attack berries and severely affected berries lose their size</li> <li>• Withering and yellowing of plants</li> </ul> | <ul style="list-style-type: none"> <li>• Field sanitation, uprooting of infested plants</li> <li>• Removal of weeds and alternate host</li> <li>• Use of effective biological control agents such as <i>Cryptolaemus montrouzieri</i> and <i>Chrysoperla carnea</i></li> <li>• Dusting of methyl parathion 2% or spraying of profenophos or chlorpyrifos</li> </ul> |

### 3. Damage and management of major pests of Tea

| Insect pest                                                     | Family :<br>Order              | Damage symptoms                                                                                                                                                                                                                                                         | Specific management practices                                                                                                                             |
|-----------------------------------------------------------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tea mosquito bug,<br><i>Helopeltis theivora</i>                 | Miridae :<br>Hemiptera         | <ul style="list-style-type: none"> <li>• Both adults and nymphs attack tender shoots, rachis, young leaves by sucking the sap</li> <li>• The affected portion shows brownish lesion</li> <li>• In heavy infestation, leaves become brittle and shoots dry up</li> </ul> | <ul style="list-style-type: none"> <li>• Collection and destruction of nymphs and adults</li> <li>• Need based spray of carbaryl or endosulfan</li> </ul> |
| Bunch caterpillar,<br><i>Andraca bipunctata</i>                 | Bombycidae :<br>Lepidoptera    | <ul style="list-style-type: none"> <li>• Caterpillars feed on leaves and cause defoliation</li> </ul>                                                                                                                                                                   | <ul style="list-style-type: none"> <li>• Manual collection and destruction of caterpillars</li> <li>• Need based spray of malathion</li> </ul>            |
| Humped slug caterpillar,<br><i>Spatulicraspeda castaneiceps</i> | Cochliidiidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Caterpillars feed on leaves and cause defoliation</li> </ul>                                                                                                                                                                   | <ul style="list-style-type: none"> <li>• Hand picking and destruction of caterpillars</li> <li>• Need based spray of malathion</li> </ul>                 |



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|                                                |                            |                                                                                                                                               |                                                                                                                                                                               |
|------------------------------------------------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Red spider mite,<br><i>Oligonychus coffeae</i> | Tetranychidae :<br>Acarina | <ul style="list-style-type: none"> <li>Mites infested leaves turn into bronze colour and if severely infested they become crumbled</li> </ul> | <ul style="list-style-type: none"> <li>Release of predators such as coccinellid beetles and <i>Chrysoperla</i> sp.</li> <li>Need based spray of sulphur or dicofol</li> </ul> |
| Purple mite,<br><i>Calaeus carinus</i>         | Eriophyidae :<br>Acarina   | <ul style="list-style-type: none"> <li>Leaves show coppery colour if attacked</li> </ul>                                                      | <ul style="list-style-type: none"> <li>Release of predators such as coccinellid beetles and <i>Chrysoperla</i> sp.</li> <li>Need based spray of sulphur or dicofol</li> </ul> |
| Pink mite,<br><i>Acaphylla theae</i>           | Eriophyidae :<br>Acarina   | <ul style="list-style-type: none"> <li>Leaves get curled and changes to yellow colour</li> </ul>                                              | <ul style="list-style-type: none"> <li>Release of predators such as coccinellid beetles and <i>Chrysoperla</i> sp.</li> <li>Need based spray of sulphur or dicofol</li> </ul> |

**4. Damage and management of major pests of Cashew nut**

| <b>Insect pest</b>                                   | <b>Family :<br/>Order</b>    | <b>Damage symptoms</b>                                                                                                                                                                                                                                            | <b>Specific management practices</b>                                                                                                                                                                                                                              |
|------------------------------------------------------|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tea mosquito bug,<br><i>Helopeltis theivora</i>      | Miridae :<br>Hemiptera       | <ul style="list-style-type: none"> <li>Both adults and nymphs attack tender shoots, rachis, young leaves by sucking the sap</li> <li>The affected portion shows brownish lesion</li> <li>In heavy infestation, leaves become brittle and shoots dry up</li> </ul> | <ul style="list-style-type: none"> <li>Collection and destruction of nymphs and adults</li> <li>Need based spray of carbaryl or endosulfan</li> </ul>                                                                                                             |
| Cashew tree borer,<br><i>Plocaederus ferrugineus</i> | Cerambycidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>Grubs enter into stem by making holes resulting in yellowing and gradual wilting of tree the bored holes with frass and excreta</li> </ul>                                                                                 | <ul style="list-style-type: none"> <li>Collection of destruction of eggs</li> <li>Burning of infested tress</li> <li>Drenching of basal trunk and root region with lindane</li> <li>Injecting carbon disulphide into the tunnels and covering with mud</li> </ul> |

## 12.4 DAMAGE AND MANAGEMENT OF MAJOR INSECT PESTS OF SPICES AND CONDIMENTS

### 1. Damage and management of major insect pests of Spices and Condiments

| Insect pest                                              | Family :<br>Order           | Damage symptoms                                                                                                                                                                                                                       | Specific management practices                                                                                                                                                                                                       |
|----------------------------------------------------------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Cardamom</b>                                          |                             |                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                     |
| Cardamon capsule borer, <i>Conoganthus punctiferalis</i> | Pyralidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>Bore hole on the pseudostem, berries with accumulation of fecal pellets</li> </ul>                                                                                                             | <ul style="list-style-type: none"> <li>Infested shoots and capsules are collected and destroyed</li> <li>Need based spray of carbaryl</li> </ul>                                                                                    |
| Cardamom hairy caterpillar, <i>Eupterote cardamomi</i>   | Bombycidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>Larvae feed on leaves voraciously and defoliate the plants</li> </ul>                                                                                                                          | <ul style="list-style-type: none"> <li>Collection and destruction of larvae</li> <li>Need based spray of malathion or carbaryl</li> </ul>                                                                                           |
| Cardamom thrips, <i>Scirtothrips cardamomi</i>           | Thripidae :<br>Thysanoptera | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from leaf sheaths and developing seeds</li> <li>The damaged capsules become malformed and scab development on pods</li> <li>Shedding of flowers and pods</li> </ul> | <ul style="list-style-type: none"> <li>Destruction of affected plants</li> <li>Release of predators such as <i>Chrysoperla</i> or coccinellid beetles</li> <li>Need based spray of acephate or fipronil</li> </ul>                  |
| Banana aphid, <i>Pentalonia nigronervosa</i>             | Aphididae :<br>Hemiptera    | <ul style="list-style-type: none"> <li>Nymphs and adults suck sap from leaves and mainly does indirect damage as vector of katte disease of cardamom</li> </ul>                                                                       | <ul style="list-style-type: none"> <li>The injection of monocrotophos into the stem</li> <li>Applying carbofuran or phorate granules at the time of planting</li> <li>Need based spray of 0.03% metasystox or dimethoate</li> </ul> |

| <b>Black pepper</b>                             |                               |                                                                                                                                                              |                                                                                                                                                                                                                                                   |
|-------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pollu beetle,<br><i>Longitarsus nigripennis</i> | Chrysomelidae :<br>Coleoptera | <ul style="list-style-type: none"> <li>• Small holes in leaves and berries of pepper</li> <li>• Drying up of spikes</li> </ul>                               | <ul style="list-style-type: none"> <li>• Tilling the soil at the base of the vines at regular intervals</li> <li>• Need based spray of dimethoate or quinalphos</li> </ul>                                                                        |
| <b>Turmeric</b>                                 |                               |                                                                                                                                                              |                                                                                                                                                                                                                                                   |
| Skipper butterfly,<br><i>Udaspes folus</i>      | Hesperiidae :<br>Lepidoptera  | <ul style="list-style-type: none"> <li>• Larvae fold the leaves and feed inside them</li> </ul>                                                              | <ul style="list-style-type: none"> <li>• Collection of butterflies with net and destroying them</li> <li>• Need based spray of quinalphos</li> </ul>                                                                                              |
| <b>Ginger</b>                                   |                               |                                                                                                                                                              |                                                                                                                                                                                                                                                   |
| Scale, <i>Aspidiotus hartii</i>                 | Diaspididae :<br>Hemiptera    | <ul style="list-style-type: none"> <li>• Nymphs suck sap and cause drying and shrinking of rhizomes</li> </ul>                                               | <ul style="list-style-type: none"> <li>• Collection and destruction of infested rhizomes</li> <li>• Release of predators such as coccinellid beetles and <i>Chrysoperla</i> sp.</li> <li>• Need based spray of dimethoate or malathion</li> </ul> |
| <b>Cinnamon</b>                                 |                               |                                                                                                                                                              |                                                                                                                                                                                                                                                   |
| Cinnamon butterfly,<br><i>Chilasia clytia</i>   | Papilionidae :<br>Lepidoptera | <ul style="list-style-type: none"> <li>• Larvae feed voraciously on lamina and leaving only mid rib</li> <li>• Plant growth is adversely affected</li> </ul> | <ul style="list-style-type: none"> <li>• Collection of butterflies with net and destroying them</li> <li>• Need based spray of quinalphos</li> </ul>                                                                                              |

## 12.5 DAMAGE AND MANAGEMENT OF MAJOR INSECT PESTS OF ORNAMENTAL CROPS

### 1. Damage and management of major pests of Ornamental crops

| Insect pest                                        | Family : Order             | Damage symptoms                                                                                                                                                  | Specific management practices                                                                                                                                                                                                                              |
|----------------------------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Jasmine bud worm, <i>Hendecasis deplifascialis</i> | Pyraustidae : Lepidoptera  | <ul style="list-style-type: none"> <li>Bore holes in the jasmine bud feeds on the inner content</li> </ul>                                                       | <ul style="list-style-type: none"> <li>Collection and destruction of infested plants</li> <li>Need based spray of dimethoate or cypermethrin</li> </ul>                                                                                                    |
| Jasmine leaf webworm, <i>Nausinoe geometralis</i>  | Pyraustidae : Lepidoptera  | <ul style="list-style-type: none"> <li>Caterpillars feed on leaves and cause skeletonization</li> </ul>                                                          | <ul style="list-style-type: none"> <li>Collection and destruction of caterpillars</li> <li>Need based spray of carbaryl or endosulfan</li> </ul>                                                                                                           |
| Jasmine eriophyid mite, <i>Aceria jasmini</i>      | Eriophyidae : Acarina      | <ul style="list-style-type: none"> <li>Feeds on leaf, petiole and stem</li> </ul>                                                                                | <ul style="list-style-type: none"> <li>Collection and destruction of infested plants</li> <li>Need based spray of dicofol or sulphur</li> </ul>                                                                                                            |
| Rose leaf cutter bee, <i>Megachile anthracina</i>  | Megachilidae : Hymenoptera | <ul style="list-style-type: none"> <li>Semicircular cuts on rose leaf</li> </ul>                                                                                 | <ul style="list-style-type: none"> <li>Need based spray of carbaryl or endosulfan</li> </ul>                                                                                                                                                               |
| Rose aphid, <i>Macrosiphum rosaeiformis</i>        | Aphididae : Hemiptera      | <ul style="list-style-type: none"> <li>Yellowing of leaves and drying of tender shoots</li> <li>Development of sooty mould due to honey dew secretion</li> </ul> | <ul style="list-style-type: none"> <li>Setting of yellow sticky traps</li> <li>Release of predators such as <i>Chrysoperla carnea</i> or <i>Coccinella septumpunctata</i></li> <li>Need based spray of dimethoate 30 EC or methyl demeton 25 EC</li> </ul> |
| Lily moth, <i>Plytela gloriosae</i>                | Noctuidae : Lepidoptera    | <ul style="list-style-type: none"> <li>Larvae feed on leaves and cause defoliation</li> </ul>                                                                    | <ul style="list-style-type: none"> <li>Collection and destruction of caterpillars</li> <li>Need based spray of carbaryl or endosulfan</li> </ul>                                                                                                           |



## Pests of Stored Products and their Management

### FUNDAMENTALS OF STORAGE OF GRAINS

The objective of proper grain storage is to maintain the characteristics that the grain possesses immediately following harvesting and drying. Thus, viability should be maintained for seed grain, milling and baking qualities should be preserved for industrially used grain, and nutritive properties should be sustained for grain fed to animals.

#### 13.1 FACTORS AFFECTING THE STORAGE OF GRAINS

The factors affecting the storage of grains can be divided into 2 major groups

- I. Abiotic (Moisture, temperature, oxygen and CO<sub>2</sub> )
- II. Biotic (Microorganisms and mites)

##### I. Abiotic

1. **Moisture** : It is necessary to know the moisture content of the grains during storage. The grain can absorb moisture from the surroundings. If the temperature is more, moisture will be reduced. The surrounding moisture is known as Relative humidity (RH). Equilibrium is developed between the RH and moisture of the grain. When the RH is 70 % the moisture content of the grain is 13.3%.

At moisture 12 % level insect attack and multiplication are faster. When the moisture is reduced all the insects will die except *Trogoderma granarium*. It can survive at low moisture and also at high temperatures. If the moisture content is more than 14 % the activity of fungus starts. The seed or grain is softened so that penetration will be easy.

2. **Temperature** : Temperature is a determining factor in the development of all

organisms and its effect is correlated with the amount of moisture present. The relative amount of moisture in the atmosphere decreases when the temperature is raised. Temperature plays an important role in the development and multiplication of the insect. When the temperature is increased the life cycle will complete in less time when grain temperature reaches 66°C the germination capacity is lost and nutritive value is decreased. Temperature below 15 °C retard insect reproduction and development if prolonged below 10°C will cause the death of most insects.

3. **Oxygen** : Like humidity and temperature every insect species requires a certain percentage of oxygen for its development and survival. When the grains are stored in an air tight storage, the oxygen content gets reduced and development of insect ceases and it dies. Khapra beetle require 16.8% oxygen content for survival of eggs, therefore its multiplication can be checked by lowering the oxygen content below this level.

Some insect can survive in absence of oxygen by reducing their metabolic rates and utilizing the oxygen in tissues.

4. **CO<sub>2</sub>** : Excessive CO<sub>2</sub> caused varied reactions in different insects. Some insects can live in an atmosphere with high CO<sub>2</sub> for several days. However an excess of this gas in the atmosphere causes growth retardation in many insects. Under high CO<sub>2</sub> concentration, the spiracles remain open leading to excessive water loss and insect dies due to desiccation.

## II. Biotic

1. **Microorganisms** : All types of stored grains are susceptible to attack by fungi. Majority of storage fungi grow quickly at some point in the temperature range of 20 °C to 40 °C and above 90% relative humidity. Fungal infection affects germination and quality of the grains.

During growth some fungi produce chemicals which are toxic to man or domestic animals. They cause liver cirrhosis. Ex: *Aspergillus flavus* produces aflatoxin on groundnut.

2. **Mites** : These are small organisms with shiny translucent body and adults possess 8 legs. A number of mites are associated with stored produces. Under suitable temperature conditions and high moisture content, they multiply rapidly to form dense populations.

Ex : The most common mite occurring in food grains is *Acarus siro*.

## 13.2 STORAGE LOSSES

### ■ Storage losses

Losses occur at different stages in the movement of food from field to the consumer

There are 2 types of grain losses

1. Quantitative
2. Qualitative

#### 1. Quantitative

- Loss of weight due to reduction in moisture content of the grain
- Loss due to grain depredation by insect, rodent and birds
- Loss due to grain mishandling

#### 2. Qualitative losses

- Discolouration of grains due to development of mould or faulty method of grain drying
- Loss due to deterioration in nutritional quality
- Due to presence of insect fragments, excreta, urine etc. A few beetle carry toxins on their body, which they are capable of imparting to the infested grains

**The factors involved in the deterioration of produce are**

- Chemical changes in produce
- Growth of microorganisms on produce
- Development of insects and mites on produce
- Feeding on produce by rodents
- Human mishandling of produce affecting quality and causing loss through spillage
- Use of poor containers and stores
- Exposure of produce to extremes of temperature and moisture

**Losses of grains can be manifested by**

- |                                    |                  |
|------------------------------------|------------------|
| 1. Weight loss                     | 2. Food loss     |
| 3. Quality loss                    | 4. Monetary loss |
| 5. Loss of good will or reputation | 6. Seed loss     |

**1. Weight loss**

- It is caused due to
- Evaporation of moisture
- Feeding of by insects, rodents and birds
- Spillage in transport

**2. Food loss**

It is caused due to

- Exposure of products to extremes of temperature and humidity during drying, processing and storage, resulting in depletion or reduction of nutrients like vitamins and amino acids
- Selective damage of grain parts by insects and microbial agents
- Insect's infestation cause severe losses in the nutritive value of the food. Weevils feed mainly on the carbohydrate portion of the maize grain reduces caloric value. Production of aflatoxins by fungus, *Aspergillus* sp. in groundnut.

**3. Quality loss**

It is due to uniformity of grain size, appearance, colour, texture and dirt.

**4. Monetary loss**

During the time of market glut, the prices of produce are usually low. For want of adequate storage facilities a farmer is forced to sell his produce at relatively low price

**5. Loss of good will**

It usually matters in international trade market. Inability to maintain the recommended standards of hygiene and quality of produce this may spoil good or reputation

**6. Seed loss**

It occurs due to physical factors such as light, moisture, temperature, mechanical factors such as damaging seed coat, or breaking of grains resulting in loss of viability. It is apparent through reduced germination, abnormal growth of rootlets and shoots and reduced vigour of the plant.



### 13.3 INSECT PESTS OF STORED PRODUCTS, THEIR DAMAGE AND MANAGEMENT

#### ■ Source of infestation

Stored grain pests have 3 sources of infestation. They are

1. In the field itself
2. Infestation in godowns from pre existing pests
3. Infestation from storage bags and containers

Insects such as rice weevil, grain moth, pulse beetles and groundnut seed beetle are carried from field to godowns.

#### The insect pests of stored gains are broadly divided into

1. **Primary grain and seed feeders:** These attack whole and undamaged grain. Larvae of these insects are confined with in one seed during development.  
Ex : Weevils, pulse beetles
2. **Secondary grain and seed feeders:** These can not attack whole grains and feed mainly on broken or already damaged grains.  
Ex : Red flour beetles
3. **Detritus and mould feeders:** These do not attack clean and sound grains. Usually moulds are necessary in the diet to complete nutritional requirements.  
Ex : Corn sap beetle

**Insect pests of stored products and their damage**

| <b>Insect</b>                                                                                | <b>Family :<br/>Order</b>     | <b>Damage symptoms</b>                                                                                                                                                                                          |
|----------------------------------------------------------------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Internal feeders</b>                                                                      |                               |                                                                                                                                                                                                                 |
| Angoumois grain moth,<br><i>Sitotroga cerealella</i>                                         | Gelichiidae :<br>Lepidoptera  | The larvae bore and feed inside the grains<br><br>The infested grains give out unpleasant smell and present an unhealthy appearance<br>The upper layer are severely attacked and grains are covered with scales |
| Rice weevil,<br><i>Sitophilus oryzae</i>                                                     | Curculionidae :<br>Coleoptera | Grubs and adults feeds inside and pupates inside and emerges by making a irregular hole through the grain                                                                                                       |
| Almond moth,<br><i>Cadra cautella</i>                                                        | Pyralidae :<br>Lepidoptera    | The larvae tunnel into the food material and feeds                                                                                                                                                              |
| Groundnut seed beetle,<br><i>Caryedon serratus</i>                                           | Bruchidae :<br>Coleoptera     | Grubs damages both pods and kernels.<br>They bore into the kernels and feed<br>Presence of exit holes on the kernels and on pods<br>Pupation takes place in silken cocoon outside                               |
| Pulse beetles,<br><i>Callosobruchus chinensis</i><br><i>C. maculatus</i><br><i>C. analis</i> | Bruchidae :<br>Coleoptera     | Adults lay individual eggs on pulses and the grubs once they emerge feed on the inner contents of pulse and pupates inside the pulse                                                                            |
| Lesser grain borer,<br><i>Rhizopertha dominica</i>                                           | Bostrychidae :<br>Coleoptera  | Grubs feed on the inner content of grains like wheat and rice and leave husk behind                                                                                                                             |
| Cigarette Beetle,<br><i>Lasioderma serricorne</i>                                            | Anobiidae :<br>Coleoptera     | Grubs and adults feed on stored tobacco, turmeric, chillies and ginger                                                                                                                                          |
| Drug store beetle,<br><i>Stegobium panaceum</i>                                              | Anodiidae :<br>Coleoptera     | Grubs feed on stored products like turmeric, ginger and coriander seeds                                                                                                                                         |
| Sweet potato weevil,<br><i>Cylas formicarius</i>                                             | Apionidae :<br>Coleoptera     | Grubs feed on the tuber by boring into it                                                                                                                                                                       |
| Potato tuber moth,<br><i>Phthorimaea operculella</i>                                         | Gelechiidae :<br>Lepidoptera  | Larvae bore into the tuber and feed on pulp<br>Attacked tuber develop bacterial infection making unfit for consumption                                                                                          |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Cigarette beetle,<br/><i>Lasioderma serricorne</i></p> <p><b>External feeders</b></p> <p>Rust red flour beetles,<br/><i>Tribolium castaneum</i>,<br/><i>T. confusum</i></p> <p>Khapra beetle, <i>Trogoderma granarium</i></p> <p>Indian meal moth, <i>Plodia interpunctella</i></p> <p>Alomond moth,<br/><i>Ephestia cautella</i></p> <p>Rice moth, <i>Corcyra cephalonica</i></p> <p><b>Secondary pests</b></p> <p>Saw toothed grain beetle, <i>Oryzaephilus surinamensis</i></p> <p>Flat grain beetle,<br/><i>Cryptolestes minutus</i></p> <p>Long headed flour beetle,<br/><i>Latheticus oryzae</i></p> | <p>Anobiidae :<br/>Coleoptera</p> <p>Tenebrionidae :<br/>Coleoptera</p> <p>Dermestidae :<br/>Lepidoptera</p> <p>Phycitidae :<br/>Lepidoptera</p> <p>Phycitidae :<br/>Lepidoptera</p> <p>Galleridae :<br/>Lepidoptera</p> <p>Cucjidae :<br/>Coleoptera</p> <p>Cucjidae :<br/>Coleoptera</p> <p>Tenebrionidae :<br/>Coleoptera</p> | <p>Both adults and grubs bore into the tobacco products<br/>They also damage furniture</p> <p>Grubs and adults feed from outside and they are serious pests of processed foods like flour, grains, dry fruits<br/>They feed on broken grains</p> <p>Grubs mainly attack stored wheat and other grains<br/>Grubs eat near the embryo region of the grains<br/>They usually remain in the top layers of the heap</p> <p>Larvae feed on grains and dried fruits under a silken web</p> <p>Larvae web the grains and feed on the grains by remaining inside the webbed grains</p> <p>Larvae web together the grains and feed within inside.<br/>Development of foul odour and the grains are unfit for consumption<br/>It also attacks broken grains and also milled products</p> <p>Grubs and adults feeds grains which are already damaged by other insects<br/>Feeding consist of scarring the roughing of surface of the grains</p> <p>Grubs feeds on broken grains</p> <p>Grubs and adults feeds on stored gains as secondary pests</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## ■ Management of insect pests of stored products

The management of stored insects is broadly classified into 3 categories

1. Preventive methods
2. Disinfestation
3. Curative methods

### 1. Preventive methods

- Spray of pyrethrum on nearly maturity crop to prevent carry over of pests from fields to godowns
- Drying of seeds under natural sunlight before storage to exposes the larva or eggs on grains and kills them
- Storing the seeds under good ventilation godowns or warehouses to prevent build up to moisture which is favorable to insects for multiplication
- Godowns floors and walls should be properly plastered to close cracks and crevices
- Bags should not placed directly on the floor but on a brick layer or wooden planks
- Store new grains in the clean godowns or receptacles

### 2. Disinfestation

- Disinfect old gunny bags by dipping them in 0.0125 per cent fenvalerate 20EC or cypermethrin 25EC
- Disinfect empty godowns or receptacles by spraying 0.05 per cent malathion
- Fumigate the godowns using 25 tablets of aluminium phosphide per 100 m<sup>3</sup> of empty space with an exposure period of 7 days
- The grain meant for seed can be protected by mixing of malathion dust 5 per cent dust @ 250 g per quintal of seed

### 3. Curative methods

- a. Traditional methods of insect control include smoking, sun-drying, admixing of dusts or ashes mixing of dusts or ashes with seeds
- b. Use of insecticides like malathion, dichlorvos, chlorpyrifos-methyl and deltamethrin as prophylactic spray on godown walls, storage surfaces etc.,
- c. Use of fumigants viz., aluminium phosphide (celphos – 3 tablets/ton of grain)
- d. Mixing of grains only with malathion WP

## 13.4 STORAGE STRUCTURES

### ■ Storage structures

Grain storage is carried out for 3 purposes. They are

- To retain a supply of food
- To service a trading system
- To retain seed for planting in the following season

Two methods of storage are used

1. In sacks
2. Loose in bulk in a variety of containers

**The choice between these two methods depend on factors such as**

- Type of produce
- Duration of storage
- Value of storage
- Climate
- Transport system
- Cost and availability of labour
- Cost of availability of sacks
- Incidence of rodent and insect infestation

**The functional requirements of storage facility are**

- To protect the grain from excessive moisture
- To protect from insects and rodent infestation
- To protect their germination and nutritive qualities
- To protect from temperature favourable to both insects and mold development
- To provide convenience and safety while moving grain in and out of storage
- To furnish facilities for inspecting the grain with out removal from storage
- To provide means for conditioning the stored grain
- To permit fumigation when required

**The main storage structures are**

1. Bamboo structures
2. Timber structures

3. Paddy straw structures
4. Mud and / or brick structures
5. Underground or pit type structures
6. Earthen storage pots
7. Oil and coaltar drums
8. Thekka storage structures

### 1. Bamboo structures

Bamboo indoor structures are called by different names in different states such as gade, duli tom or topa (Assam), thombai (Tamil Nadu), dholi (Orissa and Maharashtra) and galagi (Karnataka). Bukari and gola are the bamboo outdoor structures.

#### Advantages

- The building material and the technical know how is locally available
- The structure can be shifted because of light weight
- Suitable for storage of seeds and grains with excess moisture

#### Disadvantages

- The structures are not air tight and hence fumigation not possible
- Do not give protection against insects and rodents
- Short life and not fire proof
- Needs periodical maintenance

### 2. Timber structures

Timber indoor and outdoor structures are called by different names in different states such as peti or bin (Uttar Pradesh), gutibharal (Assam) and pathayam (Kerala).

#### Advantages

- The building material and the technical know how is locally available
- The structure can be shifted because of light weight
- Suitable for storage of seeds and grains with excess moisture

#### Disadvantages

- Do not give protection against insects and rodents, termites and moisture
- The structures are not air tight and hence fumigation not possible

### 3. Paddy straw structures

These are made of paddy straw alone or paddy straw mixed with mud. They

are called puri (Andhra Pradesh), pura (Bihar, Bengal and Punjab), morai (Bihar and Bengal)

#### **Advantages**

- Low cost
- High moisture content grain can be stored as cross ventilation provides drying

#### **Disadvantages**

- The structures are not air tight and hence fumigation not possible
- Not moisture as well as fire proof

#### **4. Mud and/or brick structures**

These are called kothas or kothis (Bihar, Punjab and Rajasthan), mud bins, bharolas or bharolis when chimney shaped and petti when box shaped (Punjab), and mud, pukka and Pusa bin.

- Pusa bin :** It is a modification of the ordinary mud storage structure commonly used in villages. To provide moisture-proof and airtight conditions, polyethylene film of 700 gauge thickness has been embedded at the top, bottom and on all the sides of the mud bin. The embedding process provides mechanical support and safety to polyethylene film. The construction of outer walls with burnt bricks up to 45 cm height makes the structure rat proof as well. The Pusa bin is constructed with unburnt bricks on burnt bricks or concrete floor to avoid rat burrowing. The bin can be constructed for storing different quantities of grain ranging from 0.4 to 3.2 tons. A round hole of 15 cm diameter is left at the bottom of the front wall to fix a pouch made up of metal sheet or polyethylene pipe, for withdrawing the grain. All the sides of inner walls are plastered and 50 cm x 50 cm clear hole at the left hand corner of the front side is left for grain filling. On top wooden pole is spread at 45 cm distance for the support of the roof. The mud slabs (made with mud, paddy husk mixed with and bamboo split) are used as top cover. The top is also covered with 5 cm layer of mud. The structure is plastered and is allowed to dry thoroughly before filling of grain. Thoroughly dried grain should be filled to full capacity. The grain and seed both remain safe in the bin for more than 1 year.
- Pusa cubicle :** This is a room like structure (3.5 m × 3.15 m × 2.60 m), a modification of Pusa bin to provide large storage capacity of 24 tons. On a platform of 3.73 m × 2.93 m × 0.07 m is made with unburnt bricks on a concrete floor (except 22 cm of outer sides with burnt bricks). A polyethylene sheet is placed on this platform and another platform of similar dimension is made with unburnt bricks. The 22 cm thick inner walls are constructed up to 2.60 m height. A wooden frame of 1.89 m × 1.06 m for door is fixed in the front side of 3.95 m wall.

The roof can be made by wooden beam placed at 15 cm distance and covered with unburnt bricks. Use of coal tar painted bamboo splits or 1.5 cm thick wooden planks followed by plaster with 5 cm thick mud could be made. Structure is then allowed to dry. A polyethylene cover is placed from the top and two edges of bottom polyethylene and of the cover are then sealed by heating. Outer wall (22 cm thick) is now constructed, the first 45cm portion with burnt bricks and the rest with unburnt bricks. The roof is constructed with brick tiles or with 5 cm thick mud mixed with paddy straw. The door is made with either plywood or seasoned wooden planks by sandwiching of polyethylene sheet which extends 10 cm all around. This is then folded on inside face of the door. A rubber gasket is fixed on this to provide complete air tightness.

#### **Advantages**

- These are cheap and handy
- These can withstand temperature fluctuations

#### **Disadvantages**

- These need regular maintenance
- Does not provide adequate locking facilities
- Not impervious to moisture, insect and fungus infestation

### **5. Under ground storage structures**

They are khatti (Uttar Pradesh, Punjab), peve (Maharashtra, Tamil Nadu, Karnataka, Madhya Pradesh), bahda, budu, khondia, koh or lathani (Madhya Pradesh), khani, banda (Rajasthan), khani (Orissa), bandha (Maharashtra)

#### **Advantages**

- Grains are free from seasonal fluctuations of temperature and humidity
- Low cost of construction compared to that of above-ground storage of similar capacity
- Ambient temperatures are relatively low and constant
- Hardly visible, and therefore relatively safe from thieves
- No need for continuous inspection
- Saves space and no danger of fire

#### **Disadvantages**

- Construction and digging are laborious
- Storage conditions adversely affect viability; the stored grains can only be used for consumption
- The grain can acquire a fermented smell after long storage



- Removal of the grain is laborious and can be dangerous because of the accumulation of carbon dioxide in the pit, if it is not completely full
- Inspection of the grain is difficult
- Risks of penetration by water
- No adequate protection against rodents and termites

#### 6. Earthen storage pots

These are indoor structures of small capacities made from burnt clay. They are made from well kneaded mud on a potters wheel, sun dried and then baked in fire. They may have both inlets and outlets or only inlets. When filled with grain, the top is sealed with mud cover. The structures are placed either slightly above the ground or partly below it. They are used in Bihar (called bhauri or kundu), Uttar Pradesh and Punjab.

##### Advantages

- These are cheap and handy
- These can withstand temperature fluctuations

##### Disadvantages

- These are fragile and likely to break easily
- Not impervious to moisture, insect and fungus infestation

#### 7. Oil and coal tar drum

These are indoor type small storage structures used in all states.

##### Advantages

- These are cheap
- These are durable

##### Disadvantages

- Does not have sufficient insulation capacity to reduce fluctuations in temperature

#### 8. Thekka storage structures

They are found mostly in UP and Rajasthan, consists of metal base at the bottom and hessian cloth container at the top

##### Advantages

- These are cheap
- These are durable

##### Disadvantages

- These are not air tight and moisture proof
- No fumigation is possible

**II. Bulk storage**

- Greater storage capacity per unit volume of the space
- Lesser difficulty in loading and unloading and involvement of cost of purchasing gunny bags
- Infestation is comparatively less in bulk storage
- The effects of temperature and humidity are minimum

**1. Godown storage**

In godowns, the grain is normally stored in gunny bags or lined with polythene sheets to check entry of pests and moisture.

**2. Modern elevator storage**

Elevator storage plants are large godowns employed for grain storage by Government agencies such as Food Corporation of India (FCI), Marketing cooperative Federation and Central and state warehouse corporation etc.

**➤ Advantages of elevator storage**

- Quicker handling of grains. An elevator is capable of handling about 180 tons per hour for both storage and simultaneous issuing
- Simultaneous storage of different kinds of grains in different silos
- All operations such as loading, unloading, weighing etc. are done mechanically
- Long storage without deterioration or loss of grains by insects and rodents
- Aeration and fumigation can be taken up and grains can be safely stored as long as 5 years
- Economy of space and saving of labour
- Fool proof arrangement in respect of physical verification of the food grains stored in silos

**13.5 GRAIN DRYING METHODS AND AERATION****■ Drying**

It is essential to dry grain quickly and effectively after harvest and before storage to retain maximum quality, to attain a moisture content sufficiently low to minimize infestation by insects and microorganisms (bacteria, fungi, etc.), and to prevent germination. The major objective in drying grains is to reduce the moisture content so that spoilage will not occur before the grain is used.

➤ **Advantages of drying**

- It reduces loss of products due to weather, insects, rodents, birds, and natural shattering.
- It allows long-term storage with little deterioration
- It permits taking advantage of possible higher prices a few months after harvest
- It provides maintenance of seed viability
- It enables the production of a better-quality product

➤ **Drying mechanism**

In the process of drying heat is necessary to evaporate moisture from the grain and a flow of air is needed to carry away the evaporated moisture. There are two basic mechanisms involved in the drying process; the migration of moisture from the interior of an individual grain to the surface, and the evaporation of moisture from the surface to the surrounding air.

The rate of drying is determined

- Moisture content
- Temperature of the grain
- Temperature and relative humidity
- Velocity of the air in contact with the grain

The different types of drying methods are

1. **Sun drying** : These make use of exposure of the wet grain to the sun and wind. Moist grains are spread in the open exposed to the sun for varying period depending up on the initial moisture and intensity of heat. Floor used for drying are either plastered with mud or bitumen or cemented.

**Disadvantages**

- Susceptible to pilferage by birds, cattle and human beings
- Requires large space
- It requires labour

2. **Solar dryers** : An improved technology in utilizing solar energy for drying grain is the use of solar dryers where the air is heated in a solar collector and then passed through beds of grain. There are two basic types of solar dryer appropriate for use with grain: natural convection dryers where the air flow is induced by thermal gradients; and forced convection dryers wherein air is forced through a solar collector and the grain bed by a fan.
3. **Drying with heated air** : This can be applied either for batch or bulk drying. In case of batch drying a definite quantity is moved in heated atmosphere for a

desired period. For bulk drying, grain is allowed to flow down in a current of hot air. Heating is done by either using furnace oil, or agricultural waste or stream. The rate of drying depends up on the rate of evaporation and diffusion when heat is applied for drying, heat is needed both to supply energy for evaporation and maintain a difference in vapour pressure to cause internal moisture to diffuse to surface.

#### 4. Drying with unheated air

This involves forcing ordinary air through the wet grain. Efficiency and cost depend on the atmospheric conditions. This drying can also be carried out when grain is stored in bins, which is known as 'in bin drying'. Bins are provided with perforated floors to facilitate drying. Air is either blown through or sucked in. Blowing or sucking is arranged taking into consideration the environment conditions and initial moisture content. Efficiency and cost would depend up on the atmospheric conditions.

##### Advantages

- Equipment required is simple
- No hazards are involved

#### 5. Mechanical dryers : These employ the application of heat from combustion of fossil fuels and biomass resources, directly or indirectly, and in both natural and forced convection systems. Mechanical dryers commonly used are batch in bin dryers, bin layered drying, batch dryers and continuous flow dryers

Air serves two basic functions in grain drying. First, the air supplies the necessary heat for moisture evaporation; second, the air serves as a carrier of the evaporated moisture. Both functions are essential, regardless of the drying system used. The amount of moisture which can be removed from grain depends on the relative humidity and temperature of the drying air, the airflow rate, and the moisture content of the grain.

### AERATION

Aeration involves forced movement of outside air through a bulk stored commodity to create a uniform temperature throughout the bulk. Cooling by aeration minimizes the growth of insect and mold populations and prevent spoilage and economic losses. In unaerated grain, the moisture from the grain is removed by air currents which condense leading to spoilage of grain.

##### ➤ Advantages

- Aeration is effective

- Aeration is safe
- Operation cost is low
- Grain quality is maintained
- No problem of resistance development

➤ **Disadvantages**

- Aeration provides only short term protection
- Poor aeration can reduce quality
- Capital investment is high
- Process of aeration is complex
- Aeration can reduce moisture

## 13.6 NON INSECT PESTS AND THEIR MANAGEMENT

### ■ **Rodents**

Rodents are omnivorous and feed on grains, vegetables, fruits, meat and other products in the houses or in the field. Rodents are responsible for causing enormous losses to crops and stored grains. Besides feeding on these products, they destroy a substantial quantity by spillage and contamination with their droppings, urine, body hair etc. Rats daily consume food equal to about 10% of their body weight, damage about 20 times the amount they actually consume, by their gnawing activity and by polluting the food grains.

The common rats found are *Rattus rattus*, *Rattus meliada*, *Rattus norvegicus*, *Mus musculus*, *Mus booduga*, *Bandicota indica* and *Bandicota bengalensis*.

➤ **Management of rodents**

#### 1. **Monitoring**

Monitoring / surveillance for the presence of rodents should be done regularly

#### 2. **Co - operation**

Control campaigns must be conducted in several adjacent areas simultaneously to coordinate and synchronize their rodent control activities for maximum effect

#### 3. **Preventive Measures**

- Sanitation :** Reduce the availability of food and shelter and other nesting places for rodents.
- Proofing :** Proofing buildings or keeping food in -rat proof containers. Floors

and walls should be kept in good repair. New holes dug by rats should be filled in immediately, with cement reinforced with pieces of crumpled chicken wire. No crevices and doors of stores should stay tightly shut when not in use

#### 4. Mechanical Control

Trapping by local traps and trusty snap trap

Trapping by sticky or glue traps (glue boards). This type of trap consists of a sticky film of glue applied to a backing of cardboard, wood or plastic

Flushing rodents out of their burrows, with smoke or by flooding them with water

Ultrasonic devices (emit ultrasonic sound waves in the 45,000 Hz). These are as a good repellent of rats and mice in buildings Ex : Varna Suraksha LX

5. **Natural Prevention (Predation)** : Normally predation by cats keep rats and mice at economic population levels

6. **Natural smoke** : Control of rodents living in burrows with natural smoke is an age old practice in India. The main principle involved in this operation is simply filling the burrows with smoke, which causes suffocation to rodents ultimately leading to their death

#### 7. Chemical control and fumigation

- The fumigants like Aluminum phosphide is effective and widely used for the control of field rodents living in burrows
- The control of rodents using rodenticides

There are two groups of rodenticides registered and available in our country. They are

- I. Acute rodenticides (Single dose and quick acting) : Example : Zinc phosphide
- II. Chronic rodenticides (Multi dose and slow acting) : Eg : Warfarin, Bromodiolone

##### I. Acute Rodenticides

- Among the acute rodenticides, Zinc phosphide and Barium carbonate are registered for use. Zinc phosphide is the only acute rodenticide available to control rodents.

##### ➤ Advantages of zinc phosphide

- Quick killing
- Small quantity of chemical is required
- Single feeding
- Population can be brought down immediately

➤ **Disadvantages of zinc phosphide**

- Necessity of prebaiting
- Low killing around 40 – 50 %,
- Induce bait shyness
- Toxic to non target species
- Chances of secondary poisoning are more

**II. Chronic Rodenticides**

- In order to overcome limitations and hazardous nature of acute rodenticides, lengthy baiting programme and possibility of resistance, new series of rodenticides have been developed and known as single dose anti-coagulants or second generation anti-coagulants. These rodenticides (Bromodiolone) combines better qualities of acute and chronic rodenticides.
- Chronic or multi-dose rodenticides (at present only anti-coagulants) are much safer than acute rodenticides because they are less toxic to the non-target species. But they have to be fed for 5 – 7 days to obtain desired results, which increases the cost of operation
- Use of anticoagulants, such as warfarin, avoids the problem of bait shyness as their mode of action is chronic and not acute.

**8. Chemosterilants**

The chemical which makes rat sterile is called a chemosterilant. Furadantine and colchicines are used as rat chemosterilants @ 0.02 g and 0.14 g respectively to make female and male rats sterile.

## 13.7 INTEGRATED MANAGEMENT OF STORAGE PESTS

**1. Monitoring**

Monitoring with pit fall traps, delta pheromone traps and probe traps and UV light trap

**2. Drying**

Ensure proper drying to bring the moisture content lower than 10% before storage

**3. Sanitation**

- Cleaning of grains and removal and destruction of infested grains
- Cleaning of storage structures and receptacle thoroughly

- Removal of loose mud plaster and apply new one to fill cracks and crevices
- Use new gunny bags for storing the grains

#### 4. Physical control

It is by exclusion, impact and removal. Exclusion by installation of proper doors of windows, preventing movement of transport vehicles in to the storage houses and use of pest exclusion meshes.

Impact : A machine used to disinfest cereals and other foods. The material is fed to the centre of a high-speed rotating disc carrying studs so that it is thrown against the studs; the impact kills any insects and destroys their eggs. The efficacy depends on speed, moisture and flow rate.

Removal by use of repellent materials such as methyl salicylate

Treating the grains with diatomaceous earth or silicon dioxide which kills the insect by abrasion and desiccation

#### 5. Botanicals

Botanicals such as *Acorus calamus* (sweet flag) can be used for protection against storage pests. It has both killing properties and deterrent properties.

#### 6. Improved storage structures

Use of improved storage structures such as Pusa bin, Pucca kothi, will reduce the insect infestation and grain can be stored for long time.

#### 7. Aerosols

Liquid formulations atomized and dispersed as small particles. Aerosols do not penetrate packaging, walls etc., but effective on exposed insects.

Ex : Methoprene and hydroprene

#### 8. Aeration

Aeration is used to either reduce the moisture or the temperature of grain. In both the situations the insect's development is arrested. Reducing moisture content through aeration is relatively easy even without the use of heated air. It is a relatively a safe technique.

#### 9. Extreme temperatures

- High temperatures** : Most of the stored grain insects die at 50 to 60°C within a period of 10 to 20 minutes. Exposure to high temperature for short time will eliminate all pests.
- Low temperature** : Temperatures between 5 and 15°C delay insect



development and are die after a very long exposure. Temperature between -1 and 3 °C can cause death in hours or days. Temperatures below -1 °C can cause death more quickly.

#### 10. Biological control

- Use of entomopathogens such as bacteria (*Bacillus thuringiensis*), fungi (*Beauveria bassiana* and *Metarrhizium anisopliae*), protozoa (*Nosema invadens* and *Farinosystis tribolii*) and NPV.
- Use of egg parasitoids such as *Trichogramma* sp. and *Uscana* sp. and parasitoids such as *Anisopteromalus calandrae*, *Lariophagus distinguendus*, *Pteromalus cerealellae* and *Theocolax elegans*
- Release of predators such as *Xylocoris flavipes*, *Teretriosoma nigrescens* and *Thaneroclerus girodi*

#### 11. Radiation

Ionizing radiation sterilizes or kills insects by damaging cells and producing free radicals. Ionizing radiation that can be used for management of stored grain pest includes gamma rays and x- rays.

Non ionizing radiation includes infrared and microwave radiation.

#### 12. Modified atmosphere

The process of changing the atmosphere of a facility artificially by inducing CO<sub>2</sub> and N<sub>2</sub>

##### ➤ Advantages and limitations of modified atmosphere

##### Advantages

- Non polluting
- Safer to apply
- No harmful residues
- Requires continuous monitoring

##### Disadvantages

- Cost of application is high
- Duration of treatment is more
- CO<sub>2</sub>, can not be used on some commodities because it forms carbonic acid which cause flavour deterioration

**13. Chemical control**

- Use of organophosphate insecticides, spinosad, juvenile hormones and diatomaceous earth
- Treating the cracks and crevices, walls and floors with dichlorvos, cyfluthrin, malathion and permethrin

**a. Grain protectants**

- Treating the grains with chlorpyrifos methyl, dichlorvos, fenitrothion, carbaryl, and pirimiphos methyl (Actellic)
- Treating the grains with insect growth regulators such as methoprene (Diacon II) and Storicide II (Reldan + deltamethrin). These give protection for 6-8 months.
- Treating the empty bins with diatomaceous earth. It is not used for treating the grains as the physical properties of grain are affected.
- Treating the grains with spinosad @2 ppm to protect grains for 2 years

**➤ Advantages and limitations of grain protectants****Advantages**

- Control of insects from months to years
- Safe application
- Effective in loosely constructed storage structures

**Limitations**

- Residue on the grains
- Requires specialized equipment

**b. Fumigation**

Fumigants give one time kill, no residual problem, highly toxic and extremely hazardous. Fumigation needs to be done repeatedly as the infestation will reoccur. Most commonly used fumigants are phosphine,  $\text{CCl}_4$ , ethylene dibromide, carbon disulfide, chloropicrin and methyl bromide.

**➤ Advantages and limitations of phosphine fumigation****Advantages of phosphine**

- It is only 1.2 times as heavy as air, so it mixes without stratifying
- It leaves least residue
- Does not interfere with germination
- It is cheap

**Limitations of phosphine**

- Repeated application is required
- Extremely toxic to mammals
- Highly corrosive
- It takes more time to kill the pests ( 3 to 7 days)
- It is not effective against eggs and pupae
- Slow development of resistance
- Requires moisture for activity

➤ **Advantages and limitations of methyl bromide fumigation**

**Advantages**

- Its highly toxic to insect pests
- Ability to penetrate commodities at ambient temperature and pressure
- It is non flammability
- Relatively short period of exposure
- Effective against all stage of insects

**Limitation**

- Extremely toxic to humans
- It is liquid and must be volatilized for application
- Heavier than air and must be recirculated after application to prevent from stratifying
- Ozone depleting agent
- It leaves residues on commodities after aeration

## **ALTERNATIVES TO METHYL BROMIDE FUMIGATION**

- Infrared treatment
- Vacuum pressure
- Ozone
- Heat treatment
- Fumigation with new fumigants such as Profume (Sulfuryl fluoride,  $\text{SO}_2\text{F}_2$ ), Ethyl formate (Vapourmate) and ecofume (mixture of phosphine 2% and carbon dioxide 98% weight)

- Controlled atmosphere: Controlled disinfestation technology involves the alteration of natural storage gases such as CO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub> so as to prevent multiplication of insects, mould growth and quality deterioration of the grains
- Mating disruption
- Use of safer chemicals such as spinosad
- Integrated approach to reduce need for fumigation





# Arthropod Vectors of Plant Diseases

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## 14.1 COMMON ARTHROPOD VECTORS

### I. Insect transmission of viral diseases

Insects are the most important group of plant virus vectors both in terms of number of viruses transmitted and in the economic importance of the disease concerned. Among Arthropod vectors approximately 99 % are insects.

The most important vectors of plant viruses are

1. Aphids
2. Leaf hoppers, plant hoppers and tree hoppers
3. Whiteflies
4. Beetles
5. Mealy bugs
6. Thrips
7. Mites

Usually viruses which are transmitted by insects are specific. Except Tobacco ring spot virus which is transmitted by thrips, mites and nematodes.

#### 1. Aphid transmission

Aphid transmissions are divided into 3 groups

- a) Non persistent (stylet borne)
- b) Semi - persistent
- c) Persistent (circulative)

**Differences between Non persistent, Semipersistent and Persistent transmission**

| <b>Non - persistent</b>                                                                                                                                                                                                                                                                                                                                      | <b>Semi - persistent</b>                                                                                                                                                                                                                                                                                                                                                  | <b>Persistent</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Acquisition period is very low (from seconds to minutes)</p> <p>No latent period</p> <p>Inoculation period is low (from seconds to minutes)</p> <p>Persistent : min - &lt; 4 hrs</p> <p>Longer feeding = less transmission</p> <p>Ability to transmit is lost between molts</p> <p>Mechanically transmissible</p> <p>Example : Mosaic - type diseases</p> | <p>Acquisition period is more (from minutes to hours)</p> <p>No latent period</p> <p>Inoculation period is more (from minutes to hours)</p> <p>Persistent : 1 - 100 hrs</p> <p>Longer feeding = longer transmission</p> <p>Ability to transmit is lost between molts</p> <p>Some are mechanically transmissible</p> <p>Example : Mosaic - and Yellows - type diseases</p> | <p>Acquisition period is more (from minutes to hours)</p> <p>Latent period is high (hours – days – weeks)</p> <p>Inoculation period is more (from minutes to hours)</p> <p>Persistent : &gt; 100 hrs</p> <p>Longer feeding = longer transmission</p> <p>Ability to transmit is retained between molts</p> <p>Mechanically not transmissible</p> <p>Example : Yellows - type and leaf - rolling diseases</p> <p>In case of propagative mode the virus retains through egg (Transovarial transmission)</p> |

**2. Leafhopper, plant hopper and tree hopper transmission**

Viruses transmitted by leaf hoppers mainly cause yellowing and a leaf rolling symptoms in the infected host plant and only a few are mechanically sap transmissible. There are no non-persistent leaf hopper transmitted virus. The viruses are most concentrated in the phloem cells and their vectors feed mainly in the phloem tissues. The virus is sucked from the infected plant into the gut of the vector, passes through the gut wall into the hemocoel circulates to the salivary glands and is finally released and transmitted in the salivary secretions.

Propagative leaf hopper transmitted viruses generally have a latent period of a week or more are retained through the moult and the vector frequently remain

viruliferous for life. Transovarian transmission takes place through eggs.

Viruses transmitted by plant hoppers are neoviruses and rhabdoviruses. Transmission by plant hopper is circulative and usually propagative

Ex :

- a) Rice tungro virus transmitted by leaf hopper, *Nephotettix virescens*
- b) Rice ragged stunt transmitted by plant hopper, *Nilaparvata lugens*
- c) Pseudo curly top disease of tomato transmitted by tree hopper, *Microtalis malleifera*

### 3. Whitefly transmission

The virus diseases transmitted by whitefly are often referred to as rugaceous and cause mosaic and leaf distortion symptoms in infected plants. The vector feed mainly on phloem tissues and the viruses are not usually sap transmitted by mechanical means. Minimal acquisition feeding period is 10 to 60 minutes but transmission efficiency increases with acquisition feeds of up to several hours. Latent period is 4 to 8 hours. Longer acquisition feeding period to acquire the virus, than the feeding period required to transmit it to a healthy plant. The vectors may retain the virus for periods ranging from 2 to 25 days. Whitefly transmission resembles the persistent and circulative transmission of aphids. These do not normally multiply within their vector (not propagative) and transovarian transmission through eggs is absent. The virus may be transmitted by both nymphs and adult whitefly.

Ex : Cotton leaf curl virus disease transmitted by whitefly, *Bemesia tabaci*

### 4. Beetle transmission

There are 4 major groups of viruses, the bromoviruses, comoviruses, tymoviruses and members of the southern bean mosaic virus group are beetle transmitted. These beetles belong to the families Chrysomelidae and Curculionidae. The beetles have biting type of mouth parts. The acquisition feeding period varies from few minutes to hours. Increased acquisition feeding times result in increased transmission. No latent period and no transovarian or transstadial transmission. The greater the duration of the acquisition feeding period, the longer the vector remains viruliferous.

Ex : Cow pea mosaic disease transmitted by *Ceratoma trifurcata*

### 5. Mealy bug transmission

Only the mealy bugs (pseudococcidae) of the various coccidae families have been reported to be virus vectors. The vector feed on the phloem cells of the host plant, but are not very efficient vectors as they are not particularly mobile and rely on crawling to move from plant to plant.

Virus transmission by mealy bugs has the characteristic of semi-persistent aphid transmission except that a starvation period prior increases the transmission efficiency of the vector.

Acquisition feeding period is about 48 to 72 hours. Three to 4 hours feeding period required for increasing transmission efficiency. The insect can retain the virus for maximum of 3 to 4 days and nymphs are more effective vectors than adults.

Ex : Cacao mottle leaf transmitted by *Planococcoides citri*

#### 6. Transmission by thrips

Thrips transmit the virus in a persistent and circulative manner. Transmission efficiency increases with acquisition feeding times from 15 minutes to 4 days. There is latent period of 4 to 16 days and vector can remain viruliferous for life. Only the nymphs can acquire and transmit the virus and transovarian passage of the virus has not been reported.

Ex : Tomato spotted wilt virus transmitted by *Frankliniella occidentalis*

#### 7. Transmission by mites

In the class of Arachnida, Eriophyid mites have been shown to be vectors of plant viruses. The transmission is circulative and not propagative. The virus persists in the vector up to 9 days and is trans-stadial but there is no evidence of transovarian transmission.

Ex : Wheat streak mosaic virus transmitted by eriophyid mite, *Aceria tulipae*

### II. Fungal diseases transmitted by insect vectors

Many flies mechanically transmit the ergot of cereals caused by *Claviceps purpurea*.

In bajra the ergot disease, *Sphacelia microcephala* is mechanically carried by insects that visit the flowers attracted by the sugary secretions feed on the fungus infected ear heads

The cotton wilt, *Fusarium vasinfectum* is transmitted through the faecal pellets of many grasshoppers like *Melanoplus differentialis* after they have fed up on the infected plant.

The common sooty mould fungus (*Capnodium* sp.) grows on the honey dew excreted by several homopterous insects like aphids, leaf hoppers, mealy bugs etc.

### III. Bacterial disease transmitted by insect vectors

Bacterial wilt of corn or Stewart's disease caused by *Xanthomonas stewartii* is reported to be transmitted by flea beetle, *Chaetocnema pulicaria* and *C. denticulata*



## 14.2 TOXICOGENIC INSECTS AND PHYTO-TOXEMIA

### ➤ Phyto - toxemia

Plant tissues are disrupted by sucking pests. Damage is very little. Toxins are injected into the plants by the insects which causes phyto-toxicity. These substances are called toxicogenics. The injury caused by such insects referred to as Toximias or phyto-toxemia or toxicoses.

Toxicogeniferous insects secrete such like substances only during some period. Individuals of species may loose ability to secrete such toxic substances under certain conditions.

Symptoms normally caused by toxicogenic insects sometimes resemble viral diseases.

### Major differences between injury caused by toxicogenic insects and symptoms of viral diseases

| Disease caused by toxicogenic insects                                               | Diseases caused by viral pathogens                                                |
|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Caused due to phytotoxic secretions of insects                                      | Caused by viruses                                                                 |
| Toxic secretions are non-reproductive in plants                                     | Virus is reproductive in plants                                                   |
| The recovery of symptom is common                                                   | Can not recover                                                                   |
| Degree of injury related to length of time and number of insects                    | Injury not related to length of time and number of insects feeding                |
| Capacity to produce is inherent in insects                                          | Capacity to produce is acquired only by feeding on diseased plant                 |
| The disease is not perpetuated by vegetative propagation or transmitted by grafting | Diseases can be perpetuated by vegetative propagation and transmitted by grafting |
| Control is proportional to the insect control                                       | Not proportional                                                                  |
| Ex : Tea mosquito bug produces enlarged stem canker on tea plants by its feeding    | Ex : Peanut bud necrosis virus transmitted by thrips                              |

### **Categories of phyto-toxemia caused in plants**

#### **I. Local lesion at the insect feeding points**

Ex : Leaf spotting, leaf stippling

#### **II. Local lesions with development of secondary symptoms**

Ex : Canker, cork formation, fruit scars, pitted seeds, aborted pods, split lesions, leaf drop, premature nut fall etc.,

#### **III. Tissue malformation**

Ex : Leaf curling, resetting, witches broom, hopper burn, phyllody, gummosis etc.,

#### **IV. Symptoms indicating translocation of casual entity**

- a. Limited translocation of toxins Ex: Chlorosis, leaf bending
- b. Systemic effect due to which whole plant is showing symptoms Ex : Wilting

#### **I. Local lesion at the insect feeding points**

Leaf spotting by coccidae

Various types of leaf spots produced by mealy bugs

- a. Pine apple mealy bug produces a circular chlorotic spot with discrete margin as the result of single insect feeding.
- b. *Empoasca* sp. produces a characteristic stippling in upper surface of leaf. It was concluded that chlorophyll disruption occurred by diffusion of salivary secretions through cell wall.
- c. Eryophid mite produces yellow spots on peaches which may be result of injection of toxic substances.

#### **II. Local lesions with development of secondary symptoms**

- a. Feeding of aphids on black raspberry results in chlorotic spotting when they feed in large numbers. The spots coalesce to form chlorotic blotch. In some instances vein clearing to form a diffused net like appearance.
- b. Tea mosquito bug produces enlarged stem canker on tea by its feeding. When it feeds on stem, water soaked area develops around point of entry of stylet with in 24 hrs canker shows as a brown oblong discolouration.
- c. Coreid bug of coconut damages coconut normally by the later instars. Insertion of stylets into bracts or young nuts causes a shrunken necrotic area which is not due to invasion of pathogen but it is direct effect of feeding.

### III. Tissue malformation

- a. *Empoasca fabae* in potato produce hopper burn symptom. Brownish area appear at tip of leaf and occasionally on margin. These area coalesce until the entire leaf margin is brown and curled. Leaflets curled and dry up petioles shortened and wither following defoliation.
- b. Eriyophid mite on mango attacks mango buds. Affected inflorescence becomes rounded, along with the terminal bud dies. The terminal buds replaced by lateral ones which also gets infested so that the stem appears stunted.

### IV. Systemic phytotoxemia

- a. Limited translocation of toxins: Toxic symptoms appear some distance from feeding site. Ex : Chlorosis, vein banding, wilting. Wilting of peach seedlings by leaf hopper. Wilting occurs several days after insects have been removed which suggest translocation of toxin from feeding point.
- b. Systemic effect due to which the whole plant show symptoms: Bean aphid feeding causes circular chlorotic area which later becomes spindle shaped which laterally extend from mid rib.

## 14.3 MANAGEMENT OF VECTORS

### 1. Elimination of source of infection

- a. Eradication of weed and other alternative hosts
- b. Rouging with in the crop
- c. Eradication of volunteer plants

### 2. Avoidance of the source of infection

- a. Modification of cropping procedures
- b. Cultivation in isolated areas
- c. Crop hygiene
- d. Use of virus free seed
- e. Use of virus free planting material

### 3. Avoidance of vector

#### Cropping in vector free areas

Potato seed crops are grown in areas not only isolated from commercial potato fields but also in areas where the aphid vectors are absent or occur in relatively low numbers

#### 4. Changes in cropping practices

Airborne virus vectors can some times be avoided by altering the sowing or transplanting date of the crop. The optimal time for planting will depend on the normal migration times of the vector so late planting will avoid early vector flights and vice versa.

Ex : Maize crop is delayed from its normal time in April to late May the incidence of virus is reduced from 45% to 3%

#### 5. Chemical control of vectors

Insecticides are more effective against viruses that are transmitted in a persistent rather than a non-persistent manner. The vectors of non-persistent viruses will eventually be killed after feeding on a plant sprayed with a systemic insecticides. However, because the virus may be transmitted within seconds of the insect starting to feed many plants may become infected before the insect dies.

Granular systemic insecticides should be used so that the active ingredients are released slowly to maximize the period over which they will protect the plant. The insecticides disulfoton and phorate are suitable.

Chemical control of vector may sometimes be achieved by destroying its weed hosts and overwintering stages.

#### 6. Non chemical control of insect vectors

##### a) Barriers and reflective mulches

Barrier crops have reported to be useful in controlling aphid transmitted viruses

Ex : Barley used as barrier plant around cauliflower reduced the incidence of aphids and cauliflower mosaic virus by 80%

Sticky, yellow polythene sheets are used for the control of aphids. The aphids are attracted to the yellow colour and are caught on the sticky polythene.

Reflective surfaces (mulches) laid on the soil around the crop plant have also been found to be highly effective in controlling aphid vectors

Ex : Aluminium strips or grey or white plastic sheets are used

The mulches are thought to act as repellent by reflecting the UV light as the aphid comes to land.

##### Disadvantages

- Expensive
- Efficiency decreases as the leaves of the plant cover the mulch
- Straw mulches can also be used which are cheap

##### b) Oil sprays

Oils such as paraffin or the mineral oils are sprayed on to the leaf surface

of plants, aphid transmission of viruses may be prevented

**Disadvantages**

- Phytotoxicity
- Continual cover of oil over the whole surface of the plant

**c) Biological control by predators**

Use of predators such as *Chrysoperla carnea* and lady bird beetles, such as *Cryptolaemus montrouzieri*, *Coccinella septumpunctata* and *Brumus suturalis*.

**7. Control by cross protection**

If a plant is deliberately infected with a mild strain of a virus it may be protected against later infection by a more severe strain of the same virus. Some yield loss may be expected from the infection by the mild strain but severe yield losses are avoided

Ex : Tristeza virus of citrus

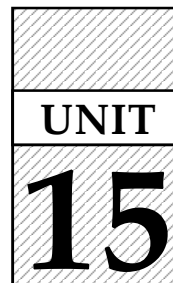
**8. Control of disease symptoms by chemicals**

Some systemic fungicides have been shown to suppress virus symptoms when applied to diseased plants with out necessarily reducing the concentration of virus with in the plant

Ex : Benlate and Bavistn reduced the severity of mosaic symptoms caused by TMV in tobacco. The chemicals were applied to the plants as a soil drench.



# Honey Bees and Bee Keeping



## 15.1 HONEY BEES SPECIES

The main honey producing bees belong to family Apidae of Hymenoptera. They are

➤ ***Apis florea* – Little honey bee**

- *Apis florea* and *Apis andreniformis* are small honey bees of southern and southeastern Asia
- They make very small vertical comb, exposed nests in trees and shrubs
- Their stings are often incapable of penetrating human skin, so the hive and swarms can be handled with minimal protection
- They produce 1/2 kg to 1 kg honey per comb
- Due to high absconding tendency they can not be kept in artificial bee hive

➤ ***Apis mellifera* - European (western, common) honey bee**

- European honey bee originated from Italy
- It is the most commonly domesticated species
- The behaviour is similar to *Apis indica*
- The average production of honey is 50 - 60 kg per hive
- It has gentle temperment and good honey gatherer
- Swarming tendency is very less
- It has revolutionized bee keeping in India

➤ ***Apis cerana indica* – Indian bee**

- It makes parallel combs on trees and rocks
- It can be easily domesticated
- Swarming tendency is very high
- Distributed all over the country up to 3000 ft above mean sea level

- On an average it produces 8- 10 kg of honey per hive
- It is susceptible to wax moth and absconding is common

➤ ***Apis dorsata* - Rock bee or gaint bee**

- They are most ferocious and they make largest hives
- They can not be kept in artificial hive
- During summer they migrate to avoid high temperature
- They make nest in trees, rocks and roof of buildings
- Swarming tendency is very high
- They produce 35 - 40 kg of honey per comb
- Efficient pollinators of agricultural and horticultural crops

## 15.2 BEE KEEPING

**Beekeeping** (or **apiculture**) is the maintenance of honey bee colonies, commonly in hives, by humans. A beekeeper (or apiarist) keeps bees in order to collect honey and beeswax, to pollinate crops, or to produce bees for sale to other beekeepers. A location where bees are kept is called an apiary.

Three types of moveable frame hive are in common use: the Newton type, the Jeolikote Villager, and the Langstroth type. Apiary honey is produced in bee hives and is harvested by extraction in honey extractors. Other types of beekeeping equipment like queen excluder, smoker, hive tool, pollen trap etc. are also required for bee keeping.

Production of honey is the major aim of bee keeping. Modern beekeeping also includes production of beeswax, bee collected pollen, bee venom, royal jelly, propolis, as also of package bees, queen bees and nucleus colonies. All these are possible only with a proper management of bees, utilizing the local plant resources and adapting to the local climatic conditions.

## 15.3 SEASONAL MANAGEMENT

➤ **Seasonal management**

It varies in different parts of the country although the basic management methods are the same.

Flow management, dearth management, provision of feeding, and control and cure of bee disorders, bee diseases, pests and enemies, are some of the routine measures to keep bee colonies healthy and strong.

Beekeeping activity depends for its success on the execution of a series of coordinated operations determined by the cycle of the seasons and successive flowering of plants. Combination of various operations – routine, seasonal and special is collectively referred to as “Bee colony Management”.

➤ **Spring season management**

Key aspects to consider during this period are

- Cleaning
- Avoid starvation
- Disease inspection
- Brood manipulation
- Re - queening
- Creating space for expansion within the hive
- swarm control
- Removal of honey crop

➤ **Off season management**

- Enough honey may be left in the hive to keep colony alive
- Protect from rain and wind
- Protect from enemies
- Take care of unhygienic conditions
- Regular inspection of colonies
- When the nectar is generally not available colonies should be given 300 to 500 ml warm sugar syrup in the evening

➤ **Summer season management**

- Provide shade to hives
- Provide clean water
- Provide sugar syrup to honey bees
- Management of pest and diseases
- Sprinkle cold water over hive
- Control robbing
- Keep colony strong
- Re - queening

➤ **Winter season management**

- Place colony under sun rays



- Plug all the openings
- Unite weaker colony with strong colony
- Keep colony strong
- Keep the entrance gate opposite to wind

## 15.4 BEE PASTURAGE

Honey bees collect nectar and pollen from flowering plants. Nectar is a sweet secretion from the floral and extra-floral nectarines of flowering and is the raw material for honey. Pollen is protein-rich food for the bees.

### ➤ Bee pasturage or bee forage

The plants that yield nectar and pollen are collectively called bee flora, bee pasturage or bee forage. The period when a good number of plants providing nectar and pollen are available to bees is called honey flow period. If the nectar yield is copious from a good number of plants of a particular species, it is called major honey flow period. When the amount of nectar to be collected is small, it is called minor honey flow period. The day when there is no honey flow is called the dearth period. As nectar and pollen are basic raw material for beekeeping means managing honey bee colonies in such a way to obtain maximum colony population to coincide with the major honey flow in an area and to utilize the population for honey production and pollination.

Plants which are good source of nectar are tamarind, moringa, neem, *Prosopis juliflora*, soapnut tree, *Glyricidia maculate*, eucalyptus, *Tribulus terrestris* and pungam.

Plants which are good source of pollen are sorghum, sweet potato, maize, tobacco, millets, coconut, roses, castor, pomegranate and date palm.

Plants which are good source of both pollen and nectar are banana, peach, citrus, guava, apple, sunflower, pear, mango and plum.

**Foraging :** Collection of nectar and pollen by bees is called foraging.

**Nectar foragers :** They collect nectar from flowers using lapping tongue and pass the nectar to hive bees. Hive bees repeatedly pass the nectar between pre oral cavity and tongue to ripen the honey later they drop the ripened honey into cells.

**Pollen foragers :** They collect pollen by passing through different flowers pollen sticking to the body is removed by using pollen comb. Then it is packed using pollen press into corbicula or pollen basket. Then the pollen is dislodged by middle

leg into cells. Pollen is mixed with honey and stored.

**Floral fidelity :** A bee visits same species of plant for pollen and nectar collection until the source is exhausted. This is known as floral fidelity.

➤ **Qualities of honey bees which make them good pollinators**

- Body is covered with hairs and has structural adaptation for carrying nectar and pollen
- Bees do not cause injury to plants
- Adult and larvae fed on nectar and pollen which is available in plenty
- They are considered as super pollinators since they store pollen and nectar for future use
- No diapause is observed and needs pollen through out the year
- Body size and proboscis length is very much suitable for many crops
- Pollinate wide variety of crops
- Forage in extreme weather conditions also

➤ **Effect of bee pollination on crops**

- It increases yield in terms of seed yield and fruit yield
- It improves quality of fruits and seeds
- Bee pollination increases oil content of seeds in sunflower
- Bee pollination is must in some incompatible crops for seed set
- Some plants such as figs, peas, seasonal flowers, chrysanthemum and many ornamental plants would produce no fruits unless pollinated by bees

➤ **Crops benefited by bee pollination**

**Fruits trees :** Almond, apple, apricot, peach, straw berry, citrus and litchi

**Vegetable crops :** Cabbage, cauliflower, carrot, coriander, cucumber, melon, onion, pumpkin, cardamom, radish and turnip

**Oil seed crops :** Sunflower, safflower, niger, sesame, rapeseed and mustard

**Forage crops :** Lucerne and clover

➤ **Management of bees for pollination**

- Place hives very near the fields
- Migrate colonies near field at 10% flowering
- Place colonies @3/ha for Italian bee and 5/ha for Indian bee

- The colonies should have 5 or 6 frames strength of bees, with sealed brood young mated queen
- Allow sufficient space for pollen and honey storage

## 15.5 BEE HIVES AND EQUIPMENTS

### ■ Bee hives

#### Modern frame hive

Frame hives are fitted with moveable frames on which the bees are persuaded to build their combs. They are usually composed of several boxes, one on top of the other, in which hive frames are suspended. The lower boxes (1-2) are used for holding the brood and the upper ones (1-2) are used for collection of honey, pollen and propolis.

The artificial comb was first introduced by Revd.L.L.Langstroth in 1851 in America. Langstroth hives use standardized sizes of hive bodies (rectangular boxes without tops or bottoms placed one on top of another) and internal frames to ensure that parts are interchangeable and that the frames will remain relatively easy to remove, inspect, and replace without killing the bees. Langstroth hive bodies are rectangular in shape and can be made from a variety of materials that can be stacked to expand the usable space for the bees. Inside the boxes, frames are hung in parallel.

Langstroth frames are thin rectangular structures made of wood or plastic and which have a wax or plastic foundation on which the bees draw out the comb. The frames hold the beeswax honeycomb formed by the bees. Ten frames side-to-side will fill the hive body and leave the right amount of bee space between each frame and between the end frames and the hive body.

Langstroth frames are often reinforced with wire, making it possible to extract honey in centrifuges to spin the honey out of the comb. As a result, the empty frames and comb can be returned to the beehive for use in the next season.

#### ➤ The modern Langstroth hive consists of the following parts

- **Hive Stand** : The upper hive components rests on this providing a landing board for the bees and helping to protect the Bottom Board
- **Bottom Board** : This has an entrance for the bees to get into the hive.
- **Brood Box** : It is the most bottom box of the hive and is where the queen bee lays her eggs.

- **Honey Super** : Usually shorter than the brood box, but is upper-most box (s) where honey is stored.
- **Frames and Foundation** : Wooden or plastic frames with wax or plastic sheets with honey comb impression where bees build wax honey combs.
- **Inner Cover** : Provides separation from outer cover and can be used as a shelf for feeding or other purposes.
- **Outer Cover** : Provides weather protection for the hive.

➤ **Various types of bee hives boxes are**

- |                                   |                   |
|-----------------------------------|-------------------|
| 1. Langstroth box (American hive) | 42.2 cm × 31.1.cm |
| 2. Pant, Kanje and jeolikote No.1 | 42.2 cm × 12.3 cm |
| 3. Dadant box (Russian hive)      | 47 cm × 28.6 cm   |
| 4. Thompson box                   | 30.5 cm × 15.2 cm |

## BEE KEEPING EQUIPMENTS

**Bee Hives** : Newton's hives, BIS hives and Marthandam hives are suited for rearing Indian bees. Langstroth hives are suited for rearing Italian bees.

The various component of the beehive should be made from suitable timber that does not emit strong smell. Kail, teak and toon are some of the suitable timbers. These are usually painted with white, blue, yellow or green.

➤ **Equipments**

The following equipment are needed for bee keeping in a apiary

**Bee veil** : Used for covering the face of bee keeper.

**Bee gloves** : Used for protecting from stinging.

**Honey scaper** : Used for scraping the bee glue and combs.

**Smoker** : Used to produce smoke to drive away the bees.

**Bee brush** : Used for brushing the bees from the honey comb before extraction.

**Honey extractor** : It is a drum like device in which uncapped frames are rotated so that the honey is extracted due to centrifugal force.

**Comb cutter** : Used for cutting and removing old and worn combs.

**Frame gripper** : Used for removing frames from bee hives.

**Queen cage :** It is simple rectangular queen introducing cage.

**Queen excluder :** It is used to separate brood chamber from the supers where honey is stored.

**Swarm bag :** It is for putting a swarm into swarm bag. The swarm bag is opened in the hive to enable the bees to occupy the frames.

**Wire embedder :** It is device used to embed the comb foundation sheet on to the wires of the hive frame.

**Uncapping basket :** It is a basket used to collect the caps of honey cells during uncapping.

**Conical queen cage :** Used for transportation of queens in conical shaped cage.

**Comb foundation :** It helps in obtaining regular strong worker brood cell comb.

**Cold uncapping knife :** It is a simple steel knife employed to remove the caps that steels the honey cells after filling before the combs are placed in the honey extractor.

**Steam uncapping knife :** Uncapping can be done more easily by a steam uncapping knife which has a double walled blade that is heated by steam.

**Uncapping basket :** It is a basket in which the caps of honey cells are collected during the uncapping. A wooden T-bar rests on its mouth to support the bottom bar of the hive frame while the uncapping is carried on.

**Wire entrance guard :** This wire gate is placed in front of the hive entrance also confines the queen inside and thus helps to prevent swarming.

**Queen cell protector :** It is a cone shaped structure made up of piece of wire wound spirally. It fits around a queen cell, giving protection to the queen inside.

**Swarm catching basket :** It is a small basket made up of bamboo and is used for collecting a sitting swarm and bringing it back to the hive.

**Drone trap :** The worker escape, where as the drones or queen, when they reach the upper compartment, can not pass through the wire screen excluder and are thus trapped, the drone are the queen trap is used for getting rid of the drones or for confining the queen just for swarming, so as to facilitate the catching of a swarm.

**Bee escape :** It is a funnel shaped structure fitted in the inner board which allows the bees to go out of the super. The bees can not come back through the narrow end and the super frames are thus cleared of the worker bees.

**Dummy board :** It is a wooden partition which fits perpendicular, just like an ordinary frame and serves as a moveable wall.

### 15.6 IMPORTANT DISEASE OF HONEY BEES

| Name of the disease                                                                                  | Casual organism                              | Place of infection     | Nature of damage / symptoms of damage                                                                              | Stage infected | Management                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------------------------------------------------------------------------------|----------------------------------------------|------------------------|--------------------------------------------------------------------------------------------------------------------|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acarine disease (Also known as <i>Isle of Wight</i> )<br>First observed on the Isle of Wight in 1904 | <i>Acarapis woodi</i> (small parasitic mite) | Trachea and body fluid | Mites live and reproduce in the trachea. They pierce the tracheal tube walls and feed on the hemolymph of the bees | Adult          | Use of grease patties (typically made from 1 part vegetable shortening mixed with 3 – 4 parts powdered sugar) placed on the top bars of the hive<br>Menthol allowed to vaporize from crystal form or mixed into the grease patties<br>Use of resistant hybrid bee known as the Buckfast bee, developed by Brother Adam at the Buckfast Abbey<br>Cotton soaked in methyl salicylate and placed under the hive in flat perforated lid<br>Destruction of effected colony |
| Amoebic disease                                                                                      | <i>Malphigamoeba mellifera</i>               | Malphigian tubules     | It causes dysentery. The cysted amoeba are passed out from intestine with faeces and contaminate the healthy bees  | Adult          | Sterilization of brood box and frames with glacial acetic acid or 40% formalin                                                                                                                                                                                                                                                                                                                                                                                        |
| Nosema disease                                                                                       | <i>Nosema apis</i> (micro-sporidian)         | Stomach                | It invades the intestinal tracts of adult bees and causes nosemosis and dysentery                                  | Adult          | Increase the ventilation through the hive and treating a hive with antibiotics<br>Removing much of the honey from the beehive then feeding the bees on sugar water<br>Sterilization of brood box and frames with glacial acetic acid or 40% formalin                                                                                                                                                                                                                  |

|                                             |                                                                                                 |                  |                                                                                                                                                                                                             |                   |                                                                                                                                                                                                                                                                        |
|---------------------------------------------|-------------------------------------------------------------------------------------------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| American Foul Brood (AFB) (Dreadly disease) | <i>Paenibacillus larvae</i> ssp. <i>larvae</i> (formerly classified as <i>Bacillus larvae</i> ) | Gut              | Infected larvae normally die after their cell is sealed. Turn dark brown and later changes into sticky mass producing foul smell (Infected larvae darken and die).                                          | Larvae            | Hive to be burned completely<br>Use of antibiotics such as oxytetracycline hydrochloride (Terramycin) and tylosin tartrate<br>Dusting the combs with sulphathiazole powder<br>Dipping the hive parts in hot paraffin wax or a 3% sodium hypochlorite solution (bleach) |
| European foul brood                         | <i>Melissococcus plutonius</i> , <i>Bacillus pluton</i> (bacterium)                             | Mid - gut        | The diseased larvae turns yellow and then brown and the tracheal system becomes visible. Larvae dies in a coiled stage causing foul smell. Cells are poorly capped and mixed with normal cells.             | Larvae            | Use of oxytetracycline hydrochloride<br>The 'Shook Swarm technique of bee husbandry can also be used to effectively control the disease                                                                                                                                |
| Chalk brood                                 | <i>Ascosphaera apis</i> (fungal disease)                                                        | Gut              | The fungus will consume the rest of the larva's body, causing it to appear white and 'chalky'                                                                                                               | Larvae            | Prevent during wet springs<br>Transfer of healthy bees into another bee hive<br>Increasing the ventilation through the hive                                                                                                                                            |
| Stone brood                                 | <i>Aspergillus fumigatus</i> , <i>A. flavus</i> and <i>A. niger</i>                             | Alimentary canal | Dead larvae turn black and become difficult to crush, hence the name stone brood<br>Fungus erupts from the integument of the larva and forms a false skin and larvae are covered with powdery fungal spores | Larvae and adults | Sterilization of the hive with formaldehyde fumes                                                                                                                                                                                                                      |

|                                         |                                                                                          |        |                                                                                                                                                                                                                                                             |                |                                                                         |
|-----------------------------------------|------------------------------------------------------------------------------------------|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------------------------------------------------------------------------|
| Sac<br>brood<br>virus<br>(SBV)          | <i>Morator<br/>aetatulas</i><br>(virus)                                                  | Skin   | Affected larvae change from<br>pearly white to gray and<br>finally black. Growth is<br>retarded. No characteristic<br>odour<br>Death occurs when the<br>larvae are upright, just<br>before pupation<br>Affected larvae are usually<br>found in capped cells | Larvae         | Destruction of affected hive<br>Sanitation of bee hive                  |
| Colony<br>Collapse<br>Disorder<br>(CCD) | Stresses,<br>malnutrition,<br>pathogens,<br>and<br>genetically<br>modified<br>(GM) crops | Colony | Worker bees from a<br>beehive colony abruptly<br>disappear                                                                                                                                                                                                  | Worker<br>bees | Exact causes are not known<br>Following organic beekeeping<br>practices |



## 15.7 IMPORTANT ENEMIES OF HONEY BEES

| Common name       | Scientific name                                   | Nature of damage                                                              | Management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------|---------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Death's hawk moth | <i>Acherontia styx</i>                            | Enters the bee hive at night and drinks up honey                              | The moths are thrown out by strong colony                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Greater wax moth  | <i>Galleria mellonella</i>                        | The caterpillars make tunnels through near the midrib of a comb during stress | It will not attack the bees directly, but feed on the wax<br>Use of para dichlorobenzene<br>Simplest way is to prevent wax moth getting into the hive through gaps and space<br>Use of traps to draw the moths away from the hive area<br>Strong hive needs no treatment to control wax moths; the bees themselves will kill and clean out the moth larvae and webs<br>Healthy hive will keep wax moth under control by ejecting the larvae<br>Wax moth larvae and eggs are killed by freezing for 24 hours<br>Wax moths can be controlled in stored comb by application of the aizawai variety of Bt ( <i>Bacillus thuringiensis</i> ) spores by spraying |
| Lesser wax moth   | <i>Achroia grisella</i>                           | The caterpillars make tunnels through near the midrib of a comb               | Lesser wax moths need warm climates to thrive hence, freezing beeswax combs reduces moth infestation<br>Fumigation with paradichlorobenzene (PDB) when combs are not filled with honey<br>Fumigation with carbon dioxide for combs that are filled with honey                                                                                                                                                                                                                                                                                                                                                                                              |
| Predatory wasps   | <i>Vespa orientalis</i><br><i>Vespa magnifera</i> | Prey on bees. The wasps macerate the bees and feed their larvae               | Destruction wasps nests by burning or with insecticides                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

|                           |                                                           |                                                                                    |                                                                                                                                                   |
|---------------------------|-----------------------------------------------------------|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Ants                      | <i>Dorylus labiatus</i> ,<br><i>Componotus compressus</i> | Take away honey and brood. Weaken and destroy the bee colony                       | Destruction of ant nests by fumigation or with insecticides<br>Treating the legs of the apiaries with a repellent                                 |
| African small hive beetle | <i>Aethina tumida</i>                                     | It lives in beehives. Comb slimed by hive beetle larvae and drive out bee colonies | Use of para dichlorobenzene<br>Use of chemical inside the corrugations of a piece of cardboard<br>Use of cooking - oil - based bottom board traps |



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| UNIT |
| 16   |

# Silkworms and Sericulture

## 16.1 SILKWORM SPECIES

| S.No. | Type of silk                              | Scientific name and family                                                             | Host                                                                                                                                           | Producing states                                                        |
|-------|-------------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| 1     | Mulberry silk (White or creamy colour)    | <i>Bombyx mori</i><br>(Bombycidae)                                                     | Mulberry plant ( <i>Morus alba</i> ,<br><i>M. indica</i> ,<br><i>M. serrata</i> and<br><i>M. latifolia</i> )                                   | Karnataka, Andhra Pradesh                                               |
| 2     | Tropical tasar silk (Copperish in colour) | <i>Antheraea mylitta</i><br>(Saturniidae)                                              | Asan ( <i>Terminalia tomentosa</i> )<br>Arjun ( <i>Terminalia arjuna</i> )<br>Saal ( <i>Shorea robusta</i> )<br>Ber ( <i>Zizyphus jujuba</i> ) | Jharkhand, Orissa, Chattisgarh, Maharastra, West Bengal, Andhra Pradesh |
| 3     | Oak tasar (Temperate)                     | <i>Antheraea proylei</i> ,<br><i>A. roylei</i> ,<br><i>A. perneii</i><br>(Saturniidae) | <i>Quercus</i> sps.                                                                                                                            | Sub Himalayan belt                                                      |
| 4     | Eri silk (Endi or Errandi) (White colour) | <i>Samia cynthia</i> ,<br><i>S. einthia</i><br>(Saturniidae)                           | Castor ( <i>Ricinus communis</i> )                                                                                                             | North eastern states, Bihar, West Bengal, Orissa                        |
| 5     | Muga silk (Golden yellow colour)          | <i>Antheraea assama</i><br>(Saturniidae)                                               | Som ( <i>Persia bombycina</i> ),<br>Sualu ( <i>Litsea polyantha</i> )                                                                          | Assam                                                                   |

## 16.2 REARING TECHNIQUES OF SILK WORMS

### 1. Mulberry silk worm rearing technique :

The grainage rooms along with its appliances should be thoroughly disinfected prior to commencement of operation and kept ready to receive seed cocoons. Immediately after the receipt of seed cocoons, they are to be spread on trays in a single layer to facilitate good aeration. Disease cocoons are rejected and healthy seed cocoons alone should be preserved in trays for further processing. Before the expected day of emergence of moths, the cocoon preservation rooms should be kept dark. After emergence, only healthy and active moths are taken for pairing and allowed for 3.5 to 4 hours of pairing. The mated female moths are placed on egg sheet and kept in dark condition for oviposition. Throughout the process of pairing, depairing and oviposition, optimum temperature of  $25 \pm 1^{\circ}\text{C}$  and relative humidity of  $75 \pm 5\%$  should be maintained.

For disinfection of eggs, egg sheets are dipped in 2 % formalin for 10 - 15 minutes. The eggs are subjected to ideal conditions of incubation. Optimum temperature of  $25 \pm 1^{\circ}\text{C}$  and relative humidity of  $75 \pm 5\%$ , 16 hours of light and 8 hours of darkness are ideal. The natural food plant of the silkworms is the mulberry tree (*Morus* sp.). Before feeding the leaves to the larvae, soak the leaves for three minutes in a cleaning solution. Thoroughly rinse the leaves in running water and shake off excess water. Store the leaves in a plastic bag in the refrigerator. The first to third instar larvae require young, tender leaves of mulberry. The fourth and fifth instar larvae will eat older mulberry leaves. The larvae undergoes 4 moults, each instar having its own duration and weight. The last instar increases in size tremendously stops feeding and start spinning cocoon. These ripe worms are then transferred to mountages (Chandrikes). The larvae suspends themselves to spirals and spin cocoons. The mature worm detaches itself from inner surface of cocoon and transforms into the pupa. The process of killing the pupa in the cocoon before they metamorphosis into moths is called stifling. Stifling is done by drying cocoons under the sun, hot air stifling or steam stifling. The process of unwinding of silk from cocoons is called reeling. Reeling is done by country charkha, cottage basin and filature. Filature is large factory where reeling of cocoons is carried out with the help of advanced technology.

### 2. Muga silkworm rearing technique :

The muga silkworms are polyphagous, semi - domesticated and multivoltine having 5 - 6 overlapping generations in a year. Seed cocoons are transferred to bamboo cages and allowed to emerge. Two to 4 copulating pairs are placed on to Kharikas to which the female is tied with thread around the shoulder joint of the right

wings and adults are allowed to mate. After mating the pair is decoupled. Kharikas with fertilized female moths are hung on the upper branches of the food trees for egg laying. The newly hatched larvae are transferred to food plants by brushing. The larvae that hatch from the eggs crawl up to the foliage and start feeding. Kharikas are shifted to newer hosts after 2-4 days of brushing. The mature worms are collected during dusk and transferred to Jalis (made up of partly dried leaves of jack fruit tied into a bundle). The jalis are then hung and left undisturbed in separate rooms till cocoons are formed. After harvesting of cocoons, seed cocoons are sorted out and the excess cocoons are subjected to stifling. Stifling is done by spreading the cocoons on bamboo mat and then exposing them to sun. This partly kills the pupa. The bamboo mat is then kept above an oven so that hot air and smoke kill the pupa fully. Degumming is done by boiling the cocoons in alkaline solution of sodium carbonate for 10 - 30 minutes. Muga cocoons are reeled on machine called Bhir.

### 3. Eri silkworm rearing technique :

Rearing is fully done in indoors. Healthy cocoons are spread on bamboo trays in a cool dark room. On hatching, active males are separated from females and allowed to mate in a dark room. Fertilized females are then tied to Kharikas by passing a thread around the shoulder joint of the right wings. Kharikas are then suspended from a string. The eggs are sterilized with 2% formalin and washed with water. The larvae hatched from these eggs are gently brushed on to trays containing cut tender leaves of castor. With the increase in age of the larvae, older leaves can be fed. One to 3rd instar stages can be reared in trays, IV and V instars are given bunch feeding. Mature worms are transferred to chandrikes or to baskets containing banana or mango leaves for cocoon formation. Cocoon are spun between the fold of leaves. Cocoon spinning takes 3-5 days. The cocoons are white or brick red tapering at one and flat rounded and open at the other end, flossy with out peduncle.

Stifling is done by spreading and exposing the cocoons to sun for 1-2 days. For degumming, cocoons are tied in a cloth sac and kept in boiling soda solution. Afterwards, it is removed, washed and dried. Being open mouthed the thread of the cocoons are discontinuous and so they are spun but not reeled. Spinning is done with a help of charkha.

The colour of eri silkworm is white or brick red. It is cheap hence called poor man's silk.

### 4. Tasar silk worm rearing technique :

The tasar silkworms are bivoltines with pupal diapause. The tasar silkworms, *Antheraea mylitta* and *A. paphia* (Lepidoptera: Saturniidae) are wild and fed on the leaves of host plant like *Terminalia tomentosa*, *Terminalia arjuna*, sal and ber.

The production of seeds and hatching of first instar larvae are the indoor operations while rearing of the worms thereafter is an outdoor operation. Single pair of moths are kept in a vessel, after mating the males are freed and females are transferred to earthen pots for egg laying. The disease free eggs are sterilized, washed, dried and kept in incubator for hatching. Rearing of I to III instar larvae is carried out in earthen vessels and IV instar larvae are transferred on to the food plants. The V instar larvae feed voraciously attains weight and stops feeding and start spinning cocoon on a twig for pupation. The silk produced by tasar silk worms is golden yellow in colour and India is leading exporter of tasar silk.

### 16.3 NUTRITIONAL REQUIREMENTS OF SILKWORMS

#### ➤ Nutritional requirements of silkworms

The food of silkworm must contain all the necessary elements for the development of the silkworm, especially for the metamorphosis. The quality of the food adversely affects the silk secretion and reproduction. The quality of mulberry leaf has a great influence on the amount ingested. Not only the physio chemical characteristics in relation to the age of the leaf but also the characteristics of the mulberry varieties, affect the amount ingested, so that qualitative underfeeding is always linked with the quantitative under feeding.

Silkworm nutrition includes organic and inorganic substances, amino acids, and variation of composition with the age of the silkworm or with the age of the leaf.

#### ➤ Organic constituents

##### **Vitamins**

**Vitamin A :** Vitamin A is effect is noted on silkworm eggs and tissues. The carotenoids of the leaves are decomposed by enzymes in the digestive tube into carotene and xanthophylls. Provitamin A so formed is changed into Vitamin A in the blood.

**Vitamin C :** Silk gland itself is very rich in vitamin C. The content of vitamin C increases from the egg to young larvae and to fifth instar larvae. Variations in the ascorbic acid ingested were noticed with the development of various organs. Vitamin C is synthesized, during the pupal stage, in the fat tissue as a result of the dehydrogenation of mannose.

**Vitamin B<sub>2</sub> :** Spraying silkworm larvae and pupae with vitamin B<sub>2</sub>, in aqueous solution,

increases the percentage of protein in the insects while the fat content decreases or remains the same.

**Vitamin B<sub>12</sub>**: The vitamin B<sub>12</sub> content in *Bombyx mori* changes according to the stage of development. It is maximum in the larvae, minimum in the eggs and organs, is greatest in the Malpighian tubules. Synthesis of cobalamine could be realized through Actinomyces in the digestive tube. Supplementation of mulberry leaves with vitamin B<sub>12</sub> increase the protide content of the larvae but not the silk production.

**Nicotinic acid**: Except for a small quantity synthesized by the intestine flora, the greater part of the required nicotinic acid is obtained by the silkworm from the mulberry leaves as is the case with tryptophan.

If mulberry leaves are supplemented with nicotamide, there is no proterogynous effect on the occurrence of the moults. However, high doses of nicotamide given to young silkworms cause loss of appetite and failure to develop normally.

Mulberry leaves treated with amino acids such as methionine and tryptophan significantly increased the fecundity, fertility, adult emergence, developmental periods and longevity of *B. mori* adults, but decreased the mortality.

➤ **Inorganic constituents**

In silkworms the abundance of potassium is more compared to sodium. In silkworm hemolymph the ratio of Na / K = 0.35 and pupa contains no sodium.

The source of sodium is food. Potassium has influence on determining the voltinism and it directly affects the egg cells in the process of development. Sodium and potassium ions acts on protein synthesis.

## 16.4 REARING HOUSE AND APPLIANCES

➤ **Rearing house :**

- A separate house is ideal for rearing of silkworms
- It should be in north and south direction and have proper ventilation
- It should be free from dampness and stagnation of water
- It should have proper humidity and exposure to bright sun light

➤ **Rearing appliances**

The following equipments needed for rearing of silk worms

**Rearing stands**: These are made up of wood used for placing the rearing trays

containing silk worms

**Feeding basin :** Used for transporting chopped leaves

**Ant wells :** The legs of the rearing stand are kept in ant wells to protect from ants

**Rearing trays :** These are made up of bamboo and used for rearing of early instars

**Paraffin paper :** Use to cover the rearing trays to maintain humidity

**Foam rubber strips :** These are kept around rearing bed to maintain humidity

**Chop sticks :** These are used to pick up younger stages of larvae

**Feathers :** These are used for brushing together newly hatched worms

**Leaf chamber :** These are used to store the mulberry leaves

**Chopping boards, knives and mats :** These are used for cutting the mulberry leaves into small pieces

**Cleaning nets :** These are used for changing different instars from rearing beds

**Mountages (Chandrikes) :** These are used for mounting last instar larvae for spinning the cocoons on to them

## 16.5 SILKWORM BREEDS

Success of sericulture depends largely on major factors like, breed, seed and feed. The silkworm breeds play an important role for high cocoon yield and silk quality. Silkworm breeds are mainly of two types namely, bivoltines and multivoltines

### 1. Bivoltines

Bivoltines silkworms go through alternating life cycles of hibernating and non hibernating eggs and complete only two life cycles in a year.

The silk obtained from bivoltines is superior with high silk content and possess longer filament length, higher neatness, cleanness, less size deviation, low boil-off ratio, higher tensile strength and less variation in evenness. Culturing bivoltine races is therefore more profitable and generally done by sericulturists.

Bivoltines races such as Kalimpong, KA, NB7, NB4D2, NB18 are commonly reared in India.

Five bivoltine breeds namely SK3, SK4, SK6, SK7 and YB have been registered in Tamil Nadu.



**2. Multivoltines**

Multivoltines races of silkworms are of great importance since they complete 5-6 life cycles in a year and develop non-hibernation eggs. Multivoltines cocoons are hard however, their yield is poor in comparison to bivoltines.

Mysore multivoltines race is reared in Karnataka, Tamil Nadu and Andhra Pradesh. Nistari multivoltines race is reared in West Bengal.

Nowadays, hybrids of multivoltines and bivoltines breeds are popular in India and other silk producing countries. Females of Mysore race and males of bivoltine KA, NB4D2 are hybridized

***Multivoltine x Bivoltine silkworm hybrids***

In India, over 95% of the commercial silk being produced is from multivoltine female  $\times$  bivoltine male parent (cross breed) and the existing cross breed Pure Mysore (PM)  $\times$  NB18 / NB4D2 has some limitation specially lower shell wt. high renditta, low cocoon shell ratio and poor fibre quality.

In order to overcome the limitations of PM  $\times$  NB4D2, new hybrids involving multivoltine breeds have been evolved.

In rainfed areas, at present multivoltine hybrid PM  $\times$  C.Nichi is being reared by the farmers which is very poor in quantitative and qualitative traits. This is replaced by BL23  $\times$  NB4D2 developed by CSR & TI, Mysore.

Five single hybrids namely, CSR2  $\times$  CSR4, CSR2  $\times$  CSR5, CSR3  $\times$  CSR6, CSR12  $\times$  CSR6 and CSR16  $\times$  CSR17 and one robust hybrid, CSR18  $\times$  CSR19 have developed by Central Silk Board for commercialization in India. Besides, one productive double hybrid, (CSR2  $\times$  CSR27)  $\times$  (CSR6  $\times$  CSR26) and one fine denier hybrid, CSR48  $\times$  CSR4 and two cocoon colour sex-limited breeds, CSR8 (SL) and CSR2 (SL) (Nandi) have been developed. CSR breeds and hybrids are being extensively reared by the farmers of South India.

Two multivoltine  $\times$  bivoltine hybrids namely RD1  $\times$  NB18 and BL23  $\times$  NB4D2 for rain-fed areas and four productive multivoltine  $\times$  bivoltine hybrids viz. P2D1  $\times$  NB18, MY1  $\times$  NB18, BL24  $\times$  NB4D2 and BL43  $\times$  NB4D2 for irrigated areas were released by Central Silk Board, Bangalore.

One multivoltine  $\times$  multivoltine hybrid, Varuna (BL24  $\times$  C. Nichi) for rain-fed areas and one multivoltine  $\times$  bivoltine hybrid, Cauvery (BL67  $\times$  CSR101) for irrigated areas have been authorized during 2005. Recently, a new promising multivoltine  $\times$  bivoltine hybrid, Jayalakshmi (ND7  $\times$  CSR2) was developed which produces higher silk yield compared to hybrid PM  $\times$  CSR2.

Three new multivoltine  $\times$  bivoltine hybrids viz. NDV6  $\times$  CSR2, ND5  $\times$  CSR2 and NP1  $\times$  CSR2 are developed which have tolerant to flacherie, high temperature and grasserie diseases respectively.

## 16.6 ENEMIES AND DISEASES OF SILKWORMS AND THEIR MANAGEMENT

### Diseases of silkworms and their management

| Disease    | Causative organism                                                                                                                                                | Susceptible stages           | Symptoms                                                                                                                                                                                                                      | Management                                                                                                                             |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Pebrine    | Sporozoa ( <i>Nosema bombycis</i> )                                                                                                                               | All stages from egg to adult | Peeper like black spots, Laying of unfertilized and dead eggs, Spotted and wrinkled skin, sluggish, swollen abdomen. The infection spreads to successive generation through eggs of diseased moth (transovarial transmission) | Mother moth examination, Use of disease free females, sterilization of eggs with 2% formalin, Destruction of infected eggs and females |
| Flacherie  | <b>Bacteria</b> ( <i>Bacillus bomby-septicus</i> )                                                                                                                | Larvae                       | Loss of appetite, semisolid excreta, becomes lethargic, skin becomes flaccid body purification and emission of foul smell                                                                                                     | Proper incubation of eggs and proper rearing conditions                                                                                |
| Grasserie  | Nuclear Polyhedrosis virus                                                                                                                                        | Larvae                       | Swelling of segments and easy rupture of skin, body fluid becomes thick and cloudy and they die                                                                                                                               | Avoidance of injury                                                                                                                    |
| Muscardine | <b>Fungus</b><br>White muscardine ( <i>Beauveria bassiana</i> )<br>Green muscardine ( <i>Spicaria prasina</i> )<br>Yellow muscardine ( <i>Iscaria farinosei</i> ) | Larvae, pupa and adult       | Hyphae come out from inter-segmental membranes, Body becomes too hard, mummified larvae vomit, diarrhoea                                                                                                                      | Proper rearing conditions and sterilization                                                                                            |

### **Enemies of silkworms and their management**

**The various enemies that attack silkworms are**

1. Uzi fly
2. Beetles
3. Ants
4. Lizards, birds, rats and squirrels

#### **1. Uzi fly, *Exorista sorbillans* (Diptera)**

The flies lay eggs on grown up larvae of silkworm and maggots on hatching eat away the body contents of caterpillar.

##### **Management**

- Prevent fly's access to silkworms by mechanical means. Fly proof rooms. All crevices of the rooms should be closed to prevent maggots pupating in the soil.
- Dusting of China clay @ 3g / 100 on spinning larvae before mounting
- Spray of Dimilin @ 1g / 0.1 square meter

#### **2. Beetles**

The adults and grubs of *Dermestes cadaverinus* (Coleoptera) and other demestid beetles are attracted to smell of the cocoons. They eat the cocoons, enclosed pupae and often the eggs of silkworms. The females lay eggs in the crevices, organic matter and wooden boards.

##### **Management**

- Closure of cracks and crevices
- Thorough cleaning of rearing room
- Fumigation of rooms with methyl bromide

#### **3. Ants**

The ants (Hymenoptera) attack silkworms in rearing trays.

##### **Management**

- Legs of the rearing stands should be dipped in ant wells (water + kerosene)
- Use of ash or kerosene at the handles of the mountages at the time of spinning

#### **4. Lizards, birds, rats and squirrels**

These feed on silkworms

##### **Management**

- Rearing rooms should be kept free from lizards
- Setting of traps for rat and squirrel control
- Scaring of birds from the vicinity

## 16.7 SERICULTURE ORGANIZATION IN INDIA

### ➤ Central Silk Board

For the development of silk industry in India, the Central Silk Board, a statutory body, is functioning under the administrative control of the Ministry of Textiles, Govt. of India, with its Headquarters at Bangalore.

#### The important functions assigned to the Board are

1. Promoting the development of silk industry by such measures as it thinks fit.
2. Undertaking, assisting and encouraging scientific, technological and economic research.
3. Devising means for improved methods of mulberry cultivation, silkworm rearing, developing and distributing healthy silkworm seeds, improving methods of silk reeling, improving the quality and production of raw silk.
4. Improving the marketing of raw silk.
5. The collection and compilation of statistics.
6. Advising the Govt. of India on all matters relating to the development of silk industry including import and export of raw silk.

#### Main Research Institutes and nested units

- Three Central Sericultural Research and Training Institutes (CSR & TIs) at Mysore (Karnataka), Berhampore (West Bengal), and Pampore (Jammu & Kashmir)
- Central Tasar Research and Training Institute, Ranchi (Jharkhand)
- Central Sericultural Germplasm Resources Centre, Hosur (Tamil Nadu)
- Silkworm Seed Technology Laboratory, Bangalore (Karnataka)
- Seri - biotech Research Laboratory, Bangalore (Karnataka)
- Central Muga Eri Research and Training Institute, Lahdoigarh (Assam)
- Ten Regional Research Stations for Mulberry, 8 for Tasar, 1 for Muga and 2 for Eri at various locations in the country.
- Forty four Research Extension Centres (REC) for Mulberry, 13 for Tasar, 3 for Muga and 2 for Eri, 1 Satellite Silkworm Breeding Station at Coonoor (TN) and 18 Sub-RECs for Mulberry and 1 Sub- REC for Muga.



# Lac Insect

UNIT

17

## 17.1 LAC INSECT

The lac insect or scale insect *Laccifer lacca* (Lacciferidae: Homoptera) secretes a resinous byproduct which is marketed as shellac.

**Life cycle :** The female lays about 300 – 500 eggs in the brood cells. The eggs hatch with few hours into tiny crimson red first instar nymphs (crawlers). The emergence of nymphs is called swarming. The nymphs crawl to reach soft succulent twigs and start sucking the plant sap voraciously and start secreting resinous secretions over the body.

Lac is secreted by the dermal glands spread all over the body except mouth parts, two breathing pores and anus. They moult thrice so that the 3<sup>rd</sup> instar nymph develops into the adult. After the first moult both males and females nymphs lose their legs antennae and eyes and become degenerate. The females stay as degenerate form and continue feeding, growing in size and secreting resin. The male is slipper like with an operculum at the rear end and female is globular. After the final moult males emerge as winged or wingless adults which mate with females and they die afterwards.

### Lac strains

They are two strains of lac insects grown in India. The Kusumi strain grown on kusum plants (*Schleichera oleon*) and Rangeeni strain grown on host plants other than kusum. The common host plant for Rangeeni strain are *Butea*, *Ziziphus* and *Shorea*

Both strains have two generations per year.

Kusumi : Jethwi (June / July to Jan / Feb) and Agani (Jan / Feb to June / July), each six months duration.

Rangeeni : Katki (Jun / July to Oct / Nov) and Baisakhi (Oct / Nov to Jun / July) four months and 8 months duration respectively.

Agani and Baisakhi are main crops contributing to 90 % of the lac production and lac obtained from Kusumi is considered superior because of light colour.

## 17.2 PRUNING

Pruning means cutting the old, weak and diseased branches. It induces the trees to give out new succulent shoots.

The following care should be taken while pruning

- Only light pruning should be carried out to avoid stunted growth
- Branches 1" or more should not be cut
- Branches ½" or less should be cut flush with point of origin on the branch or trunk
- Branches ½ to 1" thick should be cut to leave 1 ½ " long stalk
- Pruning should be done with sharp instrument to give neat cut
- Cropping should be done the way pruning is done

## 17.3 LAC PROPAGATION

When the ovisac is full of eggs appears orange at this time the twigs (brood lac) are cut from the trees of length 6 -12 inches and tied to the branches of host trees.

Cutting of lac encrusted twigs when the crop is fully mature is called harvesting. When the nymphs have escaped from the brood lac what is left is called stick lac or phunki. These sticks are kept in water for 3-4 days and raw lac is scraped from these sticks. The scraped lac is crushed lightly and washed with water to remove the impurities and it is called seed lac or chowri. The seed lac is packed into sausage shaped cloth bags. These bags are held over a charcoal fire and twisted when the lac starts melting. The molten lac flows out through the pores of the cloth leaving impurities is called as kiri behind. The pure lac is cooled down to solidify into round button shaped pieces (button lac) or stretched into thin sheets called 'shellac'. After drying the sheets, they are broken into thin small flakes called 'flake lac'. The lac is finally marketed as button lac or shellac.



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## 17.4 ENEMIES OF LAC INSECT

Two types of enemies are found with lac insects (1) Parasites and (2) Predators

### 1. Parasites

Parasites are small winged insects belong to family Chalcidae of Hymenoptera. These insects lay their eggs in the lac cells and grubs on hatching devour lac insects inside the cells

### 2. Predators

Three predators are most important

- i) Larger white lac moth, *Eublemma amabilis* (Noctuidae: Lepidoptera)
- ii) Smaller black lac moth *Holocerca pulverea* (Gelechiidae: Lepidoptera)

Both moths lay eggs on or near the lac encrusted branches. The larvae on hatching bite their way into the lac encrustation and feed on the lac insects and lac encrustations.

Both the pests are controlled by a parasites, *Microbracon greeni*

- iii) Lac wing fly, *Chrysopa* sp.

The maggots move about the lac encrustations and feed on the body contents of the lac insects.





1999

**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**

**PAPER II**

**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 3 Hours

Maximum Marks 200

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- Note.
1. All questions are COMPULSORY and carry equal marks.
  2. Answers must be written only with PEN/INK PEN in the medium specified in the admission certificate issued to the candidate.
  3. Instruction given in the admission certificate should be followed strictly.
- 

1. Describe the important morphological characters of order - Lepidoptera and discuss how they are important from agricultural point of view.
  2. Describe digestive system and the process of digestion takes place in the insect.
  3. What are principles and components of integrated pest management (IPM)? Give the IPM for the control of *Helicoverpa armigera* (Hubner) in cotton, pigeonpea and chickpea.
  4. What are biopesticides. Describe the steps involved in mass culturing of NPV. Describe the symptoms of infection and mode of action.
  5. Insects are considered as flying syringes for transmission of plant viruses. Do you agree? Discuss with suitable examples.
  6. Describe in details the structure and functions of insect integument and discuss the process of moulting.
  7. Write explanatory notes on the following :
    - (a) Detoxification mechanisms in insects
    - (b) Wing coupling mechanism
    - (c) Pheromones
    - (d) Mango leaf hoppers
    - (e) Banana Rhizome weevil
  8. Explain the mode of action of organophosphate compounds and state how it differs from carbamates.  
Give an account of advantageous and disadvantageous of synthetic pyrethroids.
  9. Enlist major pests of cotton. State how the pest scenario has changed over years with the introduction of hybrids. Present the details of accepted IPM module for the pest management of cotton.
  10. Enlist the different species of honey bees. State the production potential of each species. Present a schematic plan of improving the Agriculture industry in India.
-

**2001**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**PAPER II**

**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 3 Hours

Maximum Marks 200

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- Note.
1. All questions are COMPULSORY and carry equal marks.
  2. Answers must be written only with PEN/INK PEN in the medium specified in the admission certificate issued to the candidate.
  3. Instruction given in the admission certificate should be followed strictly.
- 

1. Give important distinguishing characters of order Lepidoptera. Name 5 important families of this order of agricultural importance giving two examples of crop pests from each of them.
2. (a) What is the importance of metamorphosis in insects? Describe the different types of metamorphosis found in insects giving suitable examples for each type.  
(b) Draw and label the typical wing venation in insects showing principal longitudinal & cross - veins.
3. Give a brief account of the organs associated with excretion in insects. Describe the mechanism and products of excretion in insects.
4. (a) Define the term natural equilibrium. Give in brief the role of biotic and abiotic factors in insect pest out break.  
(b) Give in brief the merits and demerits of biological control over chemical control.
5. (a) Enumerate various steps involved in host selection in phytophagous insects. Name important allelo chemicals acquired by plants to fight against insects.  
(b) Define the term vector giving suitable examples. Write a brief note on vector management.
6. (a) Give in brief the synaptic transmission of nerve impulse in insects.  
(b) Describe in brief the mode of action of organophosphate insecticides. How does it differ from that of carbamate insecticides ?
7. (a) Define the term IPM. Enlist the major pests attacking rape-seed/mustard and suggest a IPM package to combat them.  
(b) Give the nature of damage of following insect pests.
  - (i) Bihar hairy caterpillar
  - (ii) Gram pod borer
  - (iii) Mango leaf hopper
  - (iv) Anar butterfly
  - (v) White grub

8. What are major species of honey bee found in our country. Mention their characteristics and productivity. Write a comprehensive note on seasonal management of bees.
  9. (a) Give briefly the characteristics and significant of completely randomized, randomized block design and split plot designs applied in field experimentations in agriculture.  
(b) Give in brief the importance of CV, Replication; S.E.M., CD and Test of significance in field experimentation.
  10. (a) Differentiate between the following :
    1. Hibernation and Aestivation.
    2. Dispersal and Migration.
    3. Antagonism and Synergism.
    4. Slugs and Snails.
    5. Regression and Correlation.  
(b) Write short notes on :
    1. Wing coupling apparatus.
    2. Structural modifications of alimentary canal in Homoptera.
    3. Role of fungi in insect pest management.
    4. Diseases of silk worm and their causal organisms.
    5. Probit analysis
-

2003

**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**

**PAPER II**

**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 3 Hours

Maximum Marks 200

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- Note.
1. All questions are COMPULSORY and carry equal marks.
  2. Answers must be written only with PEN/INK PEN in the medium specified in the admission certificate issued to the candidate.
  3. Instruction given in the admission certificate should be followed strictly.
- 

1. Discuss the method involved in the mass multiplication of *Trichogramma* and preparation of trichocard. Why farmers are facing difficulties / problems in using this parasitoid ?
2. What are transgenic plants ? How they are developed ? Cite examples of transgenic plants in relation to insect resistance. List the possible drawbacks in the use of such plants.
3. Why the insecticides of chlorinated hydrocarbons. Except endosulfan, have been banned? Discuss about the decreasing trends (amount) in the use of insecticides in agriculture.
4. Discuss the mechanism of insecticide resistance in insects. How this resistance can be managed ?
5. Discuss the strategies for bee management during winter, summer and rainy seasons. How the sac brood and acarine diseases are managed ?
6. Discuss the situations in which split plot design is recommended. Give its layout and analysis.
7. Why Economic threshold level computed for an insect is area specific? Discuss it with suitable examples.
8. Differentiate between the following:
  - (a) Orthopteroid and Hemipteroid orders
  - (b) Family Arctiidae and Acrididae
  - (c) Electrodyne spraying and CDA
  - (d) Hollow cone nozzle and fish tail nozzle
  - (e) Allomones and kairomones
9. Write short notes on the following:
  - (a) Cryptobiosis
  - (b) Cryptonephridial system
  - (c) Plastron respiration
  - (d) Insect resurgence
  - (e) Mammalian selectivity ratio
10. What are biotypes ? Suggest the remedial measures to overcome the problems of biotypes.

**OR**

How the biodiversity is helpful in the management of insect pests of rice eco - system ? Discuss with suitable examples.

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**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD – 2005**

**PAPER II**

**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 3 Hours

Maximum Marks 200

1. Write in detail the physiology of excretion in insects.

**OR**

Discuss the genetic and biochemical bases of insecticide resistance in insects. How it can be managed ?

2. Write the distinguishing characters of order Lepidoptera. List ten (10) agriculturally important families with two examples (scientific name) for each.

**OR**

Give an illustrative account of female reproductive system in insects. List out the special modes of reproduction in insects with examples.

3. Describe the mode of action of organophosphorous insecticides. How it differs from that of carbamate insecticides ?

**OR**

What are insect vectors ? Write a detailed account of transmission of virus and viroid diseases in cultivated crops with suitable examples.

4. Discuss the present status of *Helicoverpa armigera* in our country and suggest the validated IPM for its Management in cotton.

**OR**

Transgenic plant is an effective tool of pest management – comment on it. Write merits and demerits of Transgenics in pest control. Indicate the present status of transgenics in our country vis-à-vis in the world.

5. Write about the innovative approaches of pest control with emphasis on pheromones, JH mimics and Ecdysone agonists.

**OR**

Write short notes on the following :

- |                            |                      |
|----------------------------|----------------------|
| (a) Insect life table      | (b) LD <sub>50</sub> |
| (c) Pesticide formulations | (d) Biotype          |

6. Write a brief account of the major insect pests of stored produce. Suggest measures for their management.
7. List out the different species of silk worms (scientific names). Write in detail about the late age mulberry silk worm rearing.
8. Explain in details the causes for the outbreak of pests in agro-ecosystem with suitable examples.
9. What is microbial control ? Discuss about the production and use of NPV for the management of *Helicoverpa armigera* and *Spodoptera litura*. Briefly explain the role of microbial control in IPM.
10. List the major pests of brinjal and okra. Suggest suitable strategies for their management.

**2006**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**PAPER II**  
**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 3 Hours

Maximum Marks 200

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- Note.
1. All questions are COMPULSORY and carry equal marks.
  2. Answers must be written only with PEN/INK PEN in the medium specified in the admission certificate issued to the candidate.
  3. Instruction given in the admission certificate should be followed strictly.
- 

1. Give an illustrative account of central nervous system in a typical insect. State different endocrine glands with their functions.
2. Write the distinguishing characters of insect order Hymenoptera. Discuss in brief the diagnostic features of any five families with examples (scientific names) and economic importance.
3. Write the mode of action of organophosphorus insecticides indicating the structure of enzyme, substrate enzyme interaction and reaction sequences. How it differs from that of carbamate insecticides in insects ?
4. List out the different biological control agents (Parasitoids, predators, viruses, bacteria, fungi & EPN) by their scientific names, important pests against which they are used and dosages. Briefly explain current status of their use in India.
5. Describe the principles of IPM. Write about the IPM of pigeonpea pod borers. List out the reasons for low adoption of IPM of crops in our country.
6. List the important pests of mango (scientific names) and write about the management of hoppers, fruit flies and nut weevil.

**OR**

Explain the concept of host plant resistance. Write briefly about the biophysical and biochemical basis of host plant resistance. List a few resistant varieties released and the pests against which they are playing crucial role in IPM.

7. Enlist various vectors and the diseases being transmitted by them in plants. Write detailed account of one important vector.

**OR**

Define insect resistance to insecticides. Write briefly about the genetic and bio-chemical basis of insecticide resistance. List out strategies you recommend to reduce or delay the development of resistance by insects to insecticides.

8. What are insect pheromones ? Enumerate different types of insect pheromones with examples.

Write about the role of sex pheromones in insect pest management and their current status of use in India.

**OR**

What are transgenic plants ? Discuss the role of transgenic technology in insect pest management and its current status in India and in the world.

9. Write the insect pests of stored products (scientific names) and their sources of infestation. Write about the prophylactic and curative measures and also the recent advances in the management of stored product pests.

**OR**

List out different species of honey bees (scientific names). Give a comparative account of Indian honey bee vis-à-vis European bee. Write about the day-to-day maintenance and management of bee colonies emphasizing the seasonal precautions to be taken.

10. Write briefly about different categories of semio-chemicals with examples. Discuss how they fit in well in integrated pest management of crops vis-a-vis conventional insecticides.

**OR**

Give an illustrative account of digestive system in insects. Describe the physiology of digestion in insects.

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**2007**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**PAPER II**

**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 3 Hours

Maximum Marks 200

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- Note.
1. All questions are COMPULSORY and carry equal marks.
  2. Answers must be written only with PEN/INK PEN in the medium specified in the admission certificate issued to the candidate.
  3. Instruction given in the admission certificate should be followed strictly.
- 

1. Define taxonomy and systematics, and write characters of class Insecta.
2. Give important characters of order, Diptera and state its economic importance
3. Enlist different types of mouth parts and illustrate the rasping and sucking type of mouth parts with examples.
4. Describe insect muscular system with suitable diagram
5. Write five main different kinds of haemocytes along with their functions.
6. Write current status of insect protective transgenic crops with special reference to India. Mention ecological risks associated with the cultivation of Bt cotton.
7. Describe insect embryogenesis and name two chemical inhibiting embryogenesis.
8. Define population dynamics and theories associated with it.

**OR**

Describe insect life tables.

9. Describe the characteristics of ideal parasitoids along with suitable examples.
10. Define entomopathogens, give examples, and mention biotechnological approaches to improve their efficacy and stability.
11. Classify the insecticides on the basis of target site mode of action and state the merits and demerits of this classification.
12. What is proinsecticide ? Give mechanism of its activation, with examples of their recommendation for crop protection.
13. What is insect biotechnology ? Describe its current status and role in IPM.
14. Define insecticide resistance and describe resistance management in the diamondback moth, *Plutella xylostella* along with role of IRAC.



15. What is insecticide metabolism ? Write its importance in toxicology. Illustrate the metabolic pathways of cypermethrin.
  16. Write the role of IGRs in insect pest management.
  17. Enlist major pests infesting cotton and describe IPM schedule.
  18. Enlist major pests of sorghum and describe bionomics of sorghum shoot fly.
  19. Give major pests of brinjal and suggest management practices for shoot and fruit borer.
  20. Describe insect pests of grapes along with management practices.
  21. State the importance and scope of sericulture in India along with important species of silkworm.
  22. (a) Enlist major insect pests of stored grain  
(b) Describe the methods for safe storage of food grains.
  23. Write short notes on:  
(a) Electrodyn sprayer  
(b) Analytical methods for pesticide residue estimation
  24. Write short notes on:  
(a) Prospects of Apiculture in India  
(b) Probit analysis
  25. Describe insect flight and metabolic fuels used for its sustenance.
-

2009

**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**

**PAPER II (Professional)**

**Subject : AGRICULTURAL ENTOMOLOGY**

Time allowed 2½ Hours

Maximum Marks 200

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**Note :** 1. Answers must be written only with BALL PEN/NK PEN in the medium specified in the admission certificate issued to the candidate.  
2. Instructions given in the admission certificate should be followed strictly.  
3. Attempt any 20 questions.  
4. Answers to the question should be brief and to the point (not more than one page of the answer book).

---

1. Discuss present status of microbial insecticides in IPM and why it is not popular with farmers ?
2. Define a species and explain the terms population, community, ecosystem and ecological niche.
3. Enlist the species of silkworms and give brief account of diseases and pests of silkworms.
4. What is an insect vector? Give the categories of vectors based on mode of transmission
5. State the principles of field experimentation. Give types of experimental designs and conditions for application of these designs.
6. What is Apiculture ? Enlist the plants suitable for bee keeping and equipments required for bee keeping
7. Write any TWO key diagnostic characters and one example for the following families.
  - (i) Thirpidae
  - (ii) Cicadellidae
  - (iii) Tephritidae
  - (iv) Acrididae
  - (v) Coccinellidae
  - (vi) Reduviidae
  - (vii) Chalcididae
  - (viii) Delphacidae
8. Enumerate the different types of insect mouth parts with examples. Explain how the mouth parts in plant bugs are modified.
9. Draw a neat labeled diagram of hypothetical wing venation showing the important veins and cross veins in an insect.
10. Draw a neat labeled diagram of an insect integument and write its functions.

11. What is metamorphosis ? Explain the different types of metamorphosis in insects.
  12. Write briefly about pest surveillance and forecasting. How it will be useful in integrated pest management ?
  13. Explain the terms Systematics, Taxonomy and Biosystematics and write the characters of class Insecta.
  14. Classify the insecticides based on their origin, mode of entry and mode of action with examples.
  15. Why the insecticides are to be formulated ? Write about the different formulations of insecticides.
  16. What are biotypes ? Describe briefly how they are developed.
  17. Write short note on the following :
    - (a) Detoxification mechanisms in insects.
    - (b) Wing coupling mechanism
    - (c) Pheromones
    - (d) Mango leaf hoppers
    - (e) Banana rhizome weevil.
  18. Define Integrated Pest Management. What is the concept of economic injury levels and how they are useful in IPM ?
  19. Describe briefly the different types of sprayings on the basis of volume of spray fluid used for unit area.
  20. Enumerate any three major pest of cotton in India and write their nature of damage. Suggest IPM for cotton pest control.
  21. Mention any three important pests on mango. Give in brief the nature of damage caused by them and write their management.
  22. List out the Coleopteran insects infesting the stored grains (with scientific names). Mention the main sources of infestation of stored grains by insects. Give the various prophylactic and curative control measures that are suggested against stored grain pests.
  23. Write in brief the various storage structures to store food grains in India. Give their merits and demerits for each of them.
  24. Explain the biology of lac insect and its inoculation methods.
  25. Describe the role of honey bees in pollination of crop plants and their impact on yields.
-

**Main ARS Examination – 2010**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

1. Write short notes on
  - (1) Association of *Wolbachia* with insects and its implication
  - (2) Significance of food in caste determination of honey bees
  - (3) Recycling of acetyl choline in synapse
2. Explain the characters of Hymenoptera, which have made them a successful and dominant order of parasitoids. Name its important families which have been exploited in the biological control of insect pests along with their genera and suitable examples.
3. Write any two key diagnostic characters and one example for the following
  - (1) Delphacidae
  - (2) Coccinellidae
  - (3) Cecidomyiidae
  - (4) Acrididae
  - (5) Noctuidae
  - (6) Ichneumonidae
4. Draw and describe the typical structure of the wing bearing segment.
5. What is metamorphosis ? Describe its various types resulting in histolysis and histogenesis.
6. What do you know about
  - (1) Haemocoelic insemination
  - (2) Polymorphism in insects
  - (3) Plastron respiration
7. What is the role of micro - organisms in insect nutrition and digestion ? Justify by giving suitable examples.
8. Explain the significance of phytochemicals in host selection by the phytophagous insects and in the tritrophic interaction.
9. How the pest scenario in rice agro - ecosystem has shifted during the last three decades and what management strategy is in vogue at present ?
10. Give synopsis of Endopterygote order and their present status with respect to sister groups.

11. Define / explain any **six** of the following :
  - (1) Xenobiotics
  - (2) Biramous appendages
  - (3) Cleptoparasitism
  - (4) Plantula
  - (5) Ptilinum
  - (6) Melanisation
  - (7) Voltinism
  - (8) Planidium
12. Differentiate between any **four** of the following :
  - (1) Piliifer and palpifer
  - (2) Polyneoptera and Paraneoptera
  - (3) Primary and secondary segmentation
  - (4) Apolysis and ecdysis
  - (5) Food chain and food web
  - (6) *Cyt* and *Cry* proteins
13. Write short notes on
  - (1) Peptide hormones in insects
  - (2) Pest surveillance in India
  - (3) Baculoviruses
14. Which insect order is most dominant and why ? Give outlines of its classification and cite important ten families of economic importance with an example to each.
15. How the typical structure of various appendages of gnathal segments has modified in different groups of insects to acquire food ?
16. What is alternation of generation and what is its significance ? Describe the complete biology of an insect pest exhibiting such life cycle.
17. Explain the concept of economic injury level and economic threshold. Give its practical use and limitations.
18. Justify the statement that insecticide resistance is a preadaptive phenomenon. Differentiate between multiple and cross resistance. Give a strategy for IRM.
19. What are invasive species ? Enlist some exotic pests, which recently have created havoc in India. Describe one such species giving its bionomics and management.
20. (a) What are principles of design of an experiment and how these are used in RBD ?  
(b) Write a short note on Probit analysis.

**Main ARS Examination – 2011**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

**Answer any 10 questions.**

**Question numbers 1 and 2 are compulsory.**

1. What is climate change ? Is it real ? What is the influence of climate change on survival of an individual insect species ? Describe the survival strategy to be adopted by insect species under changed scenario.
2. What are the principles of host plant resistance ? How can you differentiate avoidance from tolerance ? Why we should avoid cultivating 100% resistance varieties ?
3. How do insects differ from those of arachnids ? Mention three important characteristics based on which insects are classified into orders. Describe the characteristic features of Hymenoptera, and mention habits, habitats and economic importance of some of its members.
4. Describe wing venation in Braconidae, Ichneumonidae, Noctuidae, Eulophidae and Encyrtidae.
5. Mention in detail the role of heart, aorta and pulsatile organs in the process of blood circulation of a generalized insect. What are the types and functions of haemocytes in insects ? Describe the structure and characteristic features of two immunocytes.
6. What is a classical biological control (CBC) program ? Describe the importance of predator, parasitoids and pathogens in checking the pest outbreak. Explain some successful examples of CBC in various countries (at least two from each of India, USA and Australia).
7. Why do organochlorinated (OC) insecticides fail to remain in circulation ? Write an essay on ups - and - downs of OC ? Give reasons why we should ban endosulfan or otherwise ?
8. For what purpose, pheromones are utilized in pest management ? Describe different types of pheromones giving examples.
9. Enumerate the pseudococcids infesting commercial crops, their spread mechanisms and management.

10. Describe biotic and abiotic factors responsible for grain spoliage, if stored for a period of nine months.
  11. Enumerate five important host plants of the vector *Bemisia tabaci* and its management.
  12. Give a brief account of sericulture organization in India. State the problems of non - mulberry silk worms with regard to their rearing techniques and production.
  13. Define the term biopesticide. In the global pesticide industry, what is the approximate share of biopesticides ? Name important agents which occupy significant positions in the biopesticide market. Describe formulation, methods of application, advantages and disadvantages of any one of these agents ?
  14. In the rice ecosystem, what are the important pests (give their scientific names with symptoms of attack) ? How are they changing in their status during post green revolution period ? Under this context, what kind of strategy should be adopted to contain them.
  15. Write short notes on
    - (a) RBD
    - (b) Student's t - test
    - (c) Fixed and variable plot sampling
    - (d) Probit analysis
    - (e) Lac cropping
    - (f) Natality
-

**Main ARS Examination – 2012 (Memory Based)**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

**Time Allowed : 3 hrs.**

**Maximum Marks : 240**

**All Questions are compulsory.**

**A. Each question carries 2 marks**

1. Differentiate between super parasitism and hyper parasitism
2. Differentiate between vertical resistance and horizontal resistance
3. Differentiate between age specific life table and time specific life table
4. Write about some south Indian insect books and authors
5. Mention any five Acarine growth regulators?
6. Mention important insect pests of cotton?
7. Mention five important ornamental pests?
8. What is Phragmatosis?
9. Write down the mouth parts and Order of Rhynchota and Rhyneophora
10. Describe about males having behaviour of tending their eggs
11. Mention any 2 ecdysteroids?
12. Mention different types of mouth parts in insects?
13. Mention disease transmitting vectors in agricultural crops?
14. What are different components of IPM?
15. What is the Taxonomic position of Mantophasmatodea?
16. Write major diseases of silk worm?
17. Which statistical tool is used to calculate  $LD_{50}$ ?
18. Write about major available insecticidal formulations in market?
19. What are the differences between smoke and fog?
20. Different types of power operated sprayers and dusters?
21. Mention insect pests of cole crops?
22. Mention the book having chapter regarding "Effect of insecticides on natural enemies"
23. Write about non insect pests of storage?
24. Enlist storage pests of Lepidoptera?
25. Write about the vector which transmits citrus greening?
26. Differentiate between economic threshold level (ETL) vs economic injury level (EIL)
27. What is qualitative and quantitative chemical defense. Plant against herbivory.
28. What are all preventive measures in controlling storage pests?
29. What are the reasons for BPH outbreak in paddy ?



30. What are the reasons for dominance of Arthropoda ?
31. Write damage and symptoms of apple wooly aphid and San Jose scale ?
32. Differentiate between inundative releases and inoculative releases
33. What is Probit analysis ?
34. Write about different types of ovarioles ?
35. Write about important distinguishing characters of Class Insecta ?
36. Write about different species of silkworms ?
37. Name different vectors transmitting diseases ?
38. Differentiate between chilli thrips and chilli mites
39. Write about association in which both organisms are benefitted ?
40. Write about mouth parts modification in thrips ?

**B. Each question carries 5 marks**

1. What are different types of insect head orientation ?
2. What are motor neurons ?
3. Write about swarming in bees
4. Different methods of Lac extraction
5. Write about tur pod fly and castor capsule borer damage and symptoms
6. Write about different mango leaf hoppers and their symptoms
7. What are phytoplasmas ? Mention important phytoplasma diseases
8. What is replication ? Why it is necessary ?
9. What are transgenics ?
10. What is ecdysis ?
11. What are sibling species ?
12. What is silk ? What is silk yarn and its composition ?
13. Composition of insect cuticle ?
14. Rodent damage and symptoms in storage ?
15. Management of brinjal fruit and shoot borer ?

**C. Each question carries 10 marks**

1. Describe briefly about mass multiplication of *Trichogramma*
  2. Rice pests and their attacking stage, symptoms of damage and their management in India
  3. Reasons for bee swarming ? How to control bee swarming? Give outline for establishment of Apiary ?
  4. What are bulk storage structures ? Write its merits and demerits ?
  5. Write about stem borers of coffee, their symptoms of damage and their management ?
  6. Describe tritrophic interactions ?
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**Main ARS Examination – 2013 (Memory Based)**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

**Time Allowed : 3 hrs.**

**Maximum Marks : 240**

**All Questions are compulsory.**

**I. Very short answer type (2 Marks) 40 × 2 = 80**

1. What are transgenic plants ?
2. Enlist major insect pests of cardamom ?
3. Enlist different losses caused by storage insect pests ?
4. Centrifugal nozzles are used in which type of sprayers ?
5. Enlist natural enemies of papaya mealybug ?
6. Enlist two lepidopteran rice borers ?
7. Enlist the fungi effective against white grubs ?
8. Which insect order was discovered in 2002 and what is the current taxonomic status ?
9. Mention type of nozzle used for herbicidal spray ?
10. Enlist 3 groups of non-insect pests in storage ?
11. Name the insect which spreads yellow vein mosaic virus (YVMV) ?
12. What is the vector for rice tungro disease ?
13. Write the causal organism for little leaf of brinjal ?
14. Write scientific names of 3 host plants of lac insect ?
15. Honey bee egg range is from ..... to ..... per day throughout life cycle.
16. Differentiate between WPH and BPH ?
17. What is Law of priority ?
18. What are Homonyms ?
19. Write any 2 advantages of directed sprays ?
20. What is the type of resistance in which insect have the resistance against the insecticides with same chemical group ?
21. Differentiate between natural control and biological control ?
22. Differentiate between insect resistance and insecticide resistance ?
23. Mention resistance variety of chickpea against *H. armigera* ?

24. Enlist two major storage pests from Lepidoptera and 2 from Coleoptera with their scientific names ?
25. Mention special type of microorganisms present in hind gut for digestion of cellulose ?
26. Same volume of water is used in low volume and ULV sprayers (T/F)
27. *Drosophila* is used in genetic studies (T/F)
28. Lepidoptera adult scales attracts *Trichogramma* is a allomone (T/F)
29. Write about the characteristics of LSD ?
30. Enlist two soft ware statistical packages for statistical analysis?
31. Write the name of class near or close class Insecta
32. Write the name of phylum near or close to phylum Arthropoda
33. What is supraoesophageal ganglion ?
34. High value crops has low EIL (True/False)
35. Write the important pests of Jamun
36. Write the comments on univoltine in silk worm
37. If  $R$  is  $<1$  then growth rate is slow (True/False)
38. Write the definition of oligogenic and polygenic resistance
39. Directed spraying of chemical is to ——— (Reduce drift/increase drift)
40. Write about nozzles used for generating vapour?

**II. Short Answer type (5 Marks)**

**20 × 5 = 100**

1. Mention lepidopteran pests of winter vegetables and their management ?
2. Describe crops of lac on the basis of calendar year ?
3. Differentiate between ecosystem and agro-ecosystem ?
4. Describe the process of mulberry silkworm rearing ?
5. Write various steps of biological control programme ?
6. Describe uses of sex pheromones in IPM ?
7. Management of insecticide resistance ?
8. What is Host Plant Resistance ? Write briefly about the mechanisms of HPR with examples ?
9. Write definition of IPM, components of IPM and validation in Indian scenario ?
10. Differentiate between EIL and ETL ?
11. Discuss white grubs and their management in groundnut ?

12. Mention the host range of *Helicoverpa armigera* and their management?
13. Write the structure and function of Malpighian tubules?
14. Write about the significance of randomization in agriculture. Can randomization increases precision of experiment? Comments on its role?
15. Enlist five agriculturally importance insect orders with two key characters each?
16. Enlist wild and domesticated honey bee species. What are hive products?
17. Describe two factors responsible for pest outbreak?
18. What is competitive displacement? Its significance in pest management?
19. Enumerate the steps in classical biological control?
20. Write the differences between oligogenic resistance and polygenic resistance?

**III. Long answer type (10 Marks)**

**10 × 6 = 60**

1. Enlist different types of insect mouth parts with examples. Describe mouth parts structure and mechanism of feeding of red cotton bug?
  2. What is a biotype? Factors responsible for biotype development? Write about different biotypes of rice gall midge? What are the strategies to overcome biotype development?
  3. Define invasive pests? List of Invasive Alien Species (IAS) recently introduced in India? Give regions for fast establishment/colonization of IAS?
  4. Enlist insect pests of sugarcane? Highlight nature of damage, extent of losses and their management?
  5. What are novel insecticides used in pest management and enlist them. Status of botanicals in India and world. Enlist four botanicals which paved way for the development of new insecticides?
  6. Describe recent trends in storage insect pest management?
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**Main ARS Examination – 2014 (Memory Based)**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

**Time Allowed : 3 hrs.**

**Maximum Marks : 240**

**All Questions are compulsory.**

**I. Short answer type (5 Marks) 20 × 5 = 100**

1. Write briefly about aerial spraying?
2. Difference between male and female reproductive system of insect and explain with labeled diagram?
3. What are different types of life tables and what is the significance of a life table ?
4. Write note on use of pheromones in IPM ?
5. What do you mean by bio-magnification ?
6. What are the characteristics of class Insecta ?
7. Write about pesticide poisoning and measures to be taken to minimize the hazards ?
8. What is competitive displacement principle ?
9. Write a note on management white grubs ?
10. Sketch the life cycle of *Zygogramma bicolorata* and Parthenium eradication procedure ?
11. Write about life cycle and management of jute stem weevil ?
12. What are different types of insect legs ?
13. Write the differences between CRD and RBD ?
14. *Helicoverpa armigera* is serious pest. What are the reasons ?
15. Describe about sugarcane stem bores and their management ?
16. What do you mean by insecticide resistance and what measures to be taken for the management of insecticide resistance ?
17. Write Anova table of CRD ?
18. What are the different mechanisms of host plant resistance ?
19. Describe the process of moulting in insects ?

20. Write about insect pests of apple and their management ?
21. Write about different types of insecticide formulations ?
22. Differentiate between semi persistent vs persistent viral transmission ?
23. Differentiate between sympatric and allopatric species ?

**II. Long answer type (10 Marks)**

**10 × 6 = 60**

1. Preventive and curative measures of stored grain insect pest management ?
  2. Enlist the insect pests of brinjal. Damage percentage caused by fruit and shoot borer ? Write about IPM to manage those pests ?
  3. Mention pests of sugarcane along damage symptoms? Explain the IPM in sugarcane ?
  4. What is biological control ? What are different types of biological control ? Write about successful bio-control programmes in India ?
  5. Write definition of transgenics ? What are the principles of transgenic plants ? Give examples of transgenic plants ?
  6. Define IPM as per FAO. Write about ETL and EIL ?
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**ARS – 2015 Mains Examination (Memory Based)**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

**Time Allowed : 3 hrs.**

**Maximum Marks : 240**

**All Questions are compulsory.**

**I. Very short answer type (2 Marks)**

**40 × 2 = 80**

1. Name the pest that entered into India before quarantine ?
2. List out two major pests of tea.
3. List out lepidopteran pests of sunflower with authentication
4. Write briefly about the diseases of silkworm
5. What are different phases of crop protection ?
6. What are the major pests of sesamum ?
7. What do you mean by MLO and what the disease caused by them ?
8. List the centres that promote IPM in India.
9. Expand ILRI and IINGR.
10. Flit gun is used in house hold for the control of which insects and which formulation is used ?
11. What are the droplet sizes of fine spray and smoke ?
12. What is phosphine and in which form it is available ?
13. Agroecosystem is \_\_\_\_\_ in diversity and natural ecosystem is \_\_\_\_\_
14. Who is the author of “Insect Resistance in Crop Plants” and which year it was published ?
15. Underhill variety of wheat is resistance to \_\_\_\_\_ and it was bred in the year \_\_\_\_\_
16. What is the antennal type present in weevils ?
17. In Hymenoptera, meta thorax segment is fused with first abdominal segment and it is called as \_\_\_\_\_
18. Write the scientific names of castor slug and tussock caterpillar

19. Write about the growth regulators used in pest control
20. What are second generation rodenticides ?
21. Write any four pollen and nectar rich plants
22. List different strains of lac insect
23. Write about four types of insect parasitism
24. Name the tracheal system in which meta thorax and 8th abdominal segment trachea open (2 pairs)
25. Pollu beetle is a pest of \_\_\_\_\_ crop
26. When and where Zoological Survey of India (ZSI) started?
27. Wing articulation segment is \_\_\_\_\_
28. Innate capacity of insect follow uniform age distribution (True/False)
29. What are the semi-persistence diseases transmitted by whitefly?
30. What are the constraints in the implementation of IPM programme?
31. In aphids, cornicles are present in dorsum of \_\_\_\_\_ abdominal segment
32. Define Standard Error and Coefficient of Variation

**II. Short answer type (5 Marks)**

**20 × 5 = 100**

1. Write briefly about the principals of experimental design
2. Write about IPM of mustard aphid
3. What is stifling ? What is reeling ?
4. Write about management of enemies of lac insect
5. List out two insect pests attacking jute stem and their management
6. List of insect vector that spreads corn stunt and sesame phyllody
7. What is phytoplasma? What are the diseases caused by phytoplasma
8. Arrange the different categories in the classification system?
9. Write note on pregenital appendages in insects?
10. What is life table and write its significance
11. Differentiate between allomone and kairomone
12. Write about haemolymph of insects and how it is different from vertebrates?



13. Differentiate between electrodyne sprayer and control drop applicator
14. What are the advantages of aerial spraying
15. Write briefly about sterile insect technique?
16. Write about two insects of medical significance?
17. Describe briefly about the white grub management in groundnut
18. Write about the concepts of IPM
19. Write on strength of honey bee colony and functions of drones
20. What is SELECTV database ?

**III. Long answer type (10 Marks)**

**10 × 6 = 60**

1. Write about mass production of *Trichogramma* and procedure for preparation of Tricho card ? Write the reasons for the difficulties for the use of Tricho cards by the farmers
  2. What is Host Plant Resistance ? What are the mechanisms of HPR ? What the advantages and limitations of HPR ?
  3. List out any five major pests of cotton ? Write about the IPM of mealybugs of cotton ?
  4. What is insecticide resistance ? What is insect pest resurgence ? Write briefly about the different strategies for the management of insecticide resistance ?
  5. Enlist Coleopteran pests of stored products ? Write about the prophylactic, preventive and curative measures for the management of the same.
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**ARS – 2016 Mains Examination (Memory Based)**  
**AGRICULTURAL SCIENTISTS RECRUITMENT BOARD**  
**Discipline : AGRICULTURAL ENTOMOLOGY**

**Time Allowed : 3 hrs.**

**Maximum Marks : 240**

**All Questions are compulsory.**

**I. Very short answer type (2 Marks)**

**40 × 2 = 80**

1. Usefulness of silk was first given by————— empress of —————  
(Lotzu, Kwang-Ti)
2. .... is a systemic anti-feedant used against ..... (Propoxur  
(Baygon), Cotton boll weevil).
3. Mention famous Indian scientists, worked on thrips and whiteflies——— (Prof  
T. N. Ananthakrishnan, David BV)
4. Insects that are moving away from light are called as——— (Negatively  
phototrophic)
5. Ommatidia is defined as————— (Functional unit of  
compound eye)
6. Two examples of botanical insecticides——— (Neem and Pyrethrum)
7. Aggregation pheromones of pseudostem weevil of banana and red palm weevil  
of coconut (Cosmolure, Ferrulure)
8. Abbreviate i) CABI ii) PEQN (i. Centre for Agriculture and Biosciences  
International or **Commonwealth Agricultural Bureau International**, ii. Post Entry  
Quarantine Nursery)
9. World food prize winner for promotion of IPM with year (Ray F. Smith and  
Perry L. Adkisson, 1997)
10. Scolytidae are ————— (Shot hole borers)
11. Mention four sucking pests of cotton along with scientific name and family.
12. Micropyle function in insect egg is ————— (Respiration)
13. Bioluminescence function in fireflies is ————— (Species recognition  
during mating)
14. Completely parasitic order (Strepsiptera)
15. Insect order containing single genus is ————— (Zoraptera) and Insect Order  
containing three genera is ————— (Mantophasmatodea)

16. Characteristic feature of Aleyrodidae———— (Presence of vasiform orifice on pupa) and Coriidae———— (Leaf like flattening of the hind tibia)
17. Schmidt's layer found between ———— (Epidermis and Endocuticle)
18. Cell associated with setae is termed as———— (Trichogen cell)
19. Fungal pathogen of sugarcane leaf hopper and its commercial name. (*Metarrhizium anisopliae*, Pacer or Terminator)
20. Formaldehyde is a protoplasmic poison (True/False)
21. Match the year with Domestic Quarantine Act year, Locust warning Organization, Insecticides Act. DIPA (1971, 1939, 1968, 1914)
22. Matching on predators (eg. Odonota) and scavengers (eg. Mecoptera)
23. Two major body parts of Crustacea are ..... (Cephalothorax and abdomen)
24. Apneustic respiration present in———— (Parasitic Diptera, Collembola, Protura)
25. Examples of nerve poison and respiratory poison — (Carbamates, HCN)
26. First report on insecticide resistance in India?
27. NPV dose for *Spodoptera litura* is ————— (250- 500 LE or  $1.5-3.0 \times 10^{12}$  (POB/ha)
28. What is aerosol————?
29. Which is not a part in central nervous system?
30. Characteristic features of Cicadellidae and Blattidae. (Hind tibia with two or more rows of spines and run sideways; Thorax covered by pronotum and eggs are laid in ootheca)
31. Write about insect pests of guava and cashew along with the symptoms of damage?
32. What do you mean by antagonism? (If pesticides are applied in a mixture, the result may be a lower level of pest control than if either pesticide were applied alone)
33. *Opuntia* was effectively controlled the biocontrol agent ————— (*Dactylopius opuntiae*)
34. Write two examples of Ametabola and Holometabolous insects.
35. Write the definition of genetic resistance?
36. Procuticle comprises of —————and————layers (Exocuticle and Endocuticle)

**II. Short answer type (5 Marks)**

**20 × 5 = 100**

1. Define IPM (FAO). Write about survey and surveillance and their role in IPM.
2. Write about inoculative and inundative release of biocontrol agents?
3. Mention insect pests of lac and their symptoms of damage?
4. Explain the extraction procedure of shellac?
5. Write about pests and diseases of silkworm.
6. What is the basic concept of insecticide resistance?
7. Write about HPR potentialities and limitations?
8. Types of semio-chemicals and their role in IPM.
9. Types of storage structures used in India. Write about their merits and demerits?
10. Differentiate between
  - a) Hibernation and Aestivation
  - b) Dispersal and Migration
  - c) Diapause and Quiescence
  - d) Correlation and Regression
11. High volume spaying and low volume spraying –Write about the merits and demerits
12. Write down any five pollinators other than honey bees. What are crops that need insect pollination ?
13. Write about the factors effecting specificity of a vector ?
14. What is silk ? What are the equipments needed for silkworm rearing ?
15. What is the need of a formulation ? Write about different formulations of insecticides ?
16. Write about sweet potato weevil and the sex pheromone and kairomone using for their management.
17. Write a short notes on mango nut weevil?
18. What are the difference between early shoot borer and top shoot borer of sugarcane ?
19. Write a note on honey bee foraging activity.
20. Write briefly about univoltine and bivoltine silk worms

**III. Long answer type (10 marks)**

**10 × 6 = 60**

1. Write about biological control of weeds along with success stories.
  2. Mention the insect pests of rapeseed and mustard and write about the IPM.
  3. Write a note on Indian honey bee species and their productivity. Explain about the seasonal management of honey bee colonies.
  4. Global climate change and its effect on insect pests
  5. Mention any two cotton pests and write the management practices
  6. Write down the coleopteran pests of stored grains. What are prophylactic and curative measures to be taken?
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### Other Useful Books

| Name of book                                                                     | Price (₹) |
|----------------------------------------------------------------------------------|-----------|
| • Agriculture a competitive approach – Gopal Lal Choudhary                       | 280       |
| • Agri Facts – Agricultural Economics – S. V. Sai Prasad                         | 350       |
| • Agri Facts – Agronomy – S. V. Sai Prasad, S. R. Kantwa                         | 300       |
| • Agri Facts – Biotechnology – S. V. Sai Prasad                                  | 350       |
| • Agri Facts – Objective Entomology & Nematology – S. V. Sai Prasad              | 320       |
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| • An Introduction to Agricultural Social Science – Subhash Chandra, Suresh Kumar | 600       |
| • Applied Entomology – D.S. Reddy                                                | 260       |
| • Entomology Treatise – Dr. T. V. Prasad                                         | 300       |
| • Glaustas Horticulture – Muthukumar, Selvakumar                                 | 480       |
| • Krishi Vigyan (Hindi) – Dr. S. R. Kantwa, C.M. Parihar                         | 430       |
| • MCQs in Agriculture Extension – Sunil V. G.                                    | 300       |
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| • Objective Agriculture for A.R.S. – Dr. S. R. Kantwa                            | 430       |
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| • Concise Agriculture – C.R.Kantwa                                               | 530       |
| • Concise Agronomy – C.R.Kantwa                                                  | 530       |
| • Competitive Forestry – Uthappa AR                                              | 440       |
| • BSc Agriculture Entrance exam. – Dr. Lalita Gaur                               | 320       |
| • IBPS - SO Agriculture Field Officer – Lalita Gaur                              | 260       |
| • Objective Sericulture – Dr. Firdos Ahmad Malik                                 | 300       |
| • Entomology - an overview – Kalpana Bisht                                       | 410       |
| • A Guide on Descriptive Entomology – K. Shankarganesh                           | 360       |
| • Objective Agricultural Entomology – Dr. Shravan Haldhar                        | 410       |
| • Fundamentals of Agriculture Entomology – Shravan M. Haldhar                    | 410       |



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